PHYSICS

PART III

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CHAPTER 1

Oscillatory Motion and Sound

§ 1. Introduction to Oscillatory Motion

You know already about the translatory and rotatory motion. In nature, technology and engineering we come across a still another type of motion. Under the action of the wind the branches and leaves of trees move to and fro. A similar motion is performed by the needle of sewing machine or by the pendulum of a wall clock. In the laboratory you can observe that the pans of a balance move up and down when disturbed. You also know the to and fro motion of a simple pendulum (Fig. 1.1).

What do you find common in all the above illustrations of motion? You must have noticed that in all these illustrations the body moves about a certain position of equilibrium. First it goes to one side of this position. It stops after moving through a certain distance in this direction. Then the body returns along the same path to the position of equilibrium. It now goes to the other side almost the same distance and stops. Again it comes to the position of equilibrium and moves ahead. This motion is repeated.

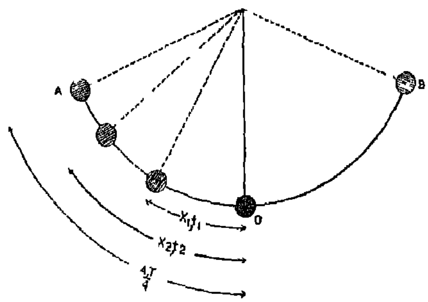


Fig. 1.1. Motion of simple pendulum.

Thus the simple pendulum, in Fig. 1.1. starts from the extreme position *A*. From A it reaches the position of equilibrium *O*. Then it moves to the other side up to *B*. Again it travels the same path backwards along *BOA*. This is repeated many times.

In Physics such a motion is called *Oscillatory Motion.*

§ 2. Characteristics of an Oscillatory Motion

There are some quantities which are essential for the description of a oscillatory motion. To understand them, let us consider the motion of a simple pendulum, shown in Fig. 1.1.

1. The *displacement* is the dis-

tance of the oscillating body from the position of rest at a given instant of time. The displacement is denoted by the letter x. Thus in Fig. 1.1, x_1 is the displacement at the instant t_1, x_2 at the instant t_2 etc. The displacement is usually measured in cm.

2. The maximum displacement of an oscillating body from the position of equilibrium is called the *amplitude* of oscillation. It is usually denoted by the letter A. Thus in Fig. 1 1, the amplitude of the pendulum is equal to either OA or OB. The amplitude is usually measured in cm.

3. Starting from any point, when the oscillatory body comes next to the same position and is moving in the same direction, it is said to have completed one full oscillation. For instance, in Fig. 1.1, let the pendulum bob start from O towards A. It reaches A, turns back and traversing the same path comes back to the point O. Here it is at the starting point but is not moving in the same direction. It is now going towards B, whereas previously it was going towards the point A. From O it reaches B. Next from B it reaches the starting point O and is now moving towards the point A. It has now performed one full oscillation. Now the next oscillation will start. The time required to perform one full oscillation is the *periodic time*. This is denoted by T. Usually the periodic time is measured in seconds.

4. Now consider a pendulum for which the periodic time is 2 sec. Ask yourself a question : How many ~~full~~ oscillations this pendulum makes in one second ? The answer is 1/2 oscillation. Note that this number is just the reciprocal of the periodic time in seconds. Now consider another pendulum with periodic time 10 sec. The bob of this pendulum will do only 1/10th of a full oscillation in one second. Now if the periodic time is 1/30 sec., how many full oscillations will be performed by the pendulum per second ? Naturally 30 oscillations per second. Thus the number expressing the oscillations per second is just the reciprocal of the number giving periodic time in seconds. The number of oscillations per second is called the *frequency* of the oscillatory motion. It is usually denoted by f. The unit of frequency is oscillation or cycle per second, i.e., Cycle/Second or in short C/S. Thus the three pendulums with values of periodic time equal to 2, 10 and 1/30 sec. have frequency 1/2, 1/10 and 30 C/S respectively.

Amplitude, periodic time and

frequency are the characteristics of any oscillatory motion. We have noted above that the periodic time T and frequency f are reciprocals of each other.

$$\text{Hence } f = \frac{1}{T} \text{ and } T = \frac{1}{f}.$$

§ 3. Oscillations of a Horizontal Spring Pendulum

Tracing the vibrations

Let us observe the characteristics of an oscillatory motion of a horizontal spring pendulum. One end of the spring is kept fixed. To the other end of the spring a sphere B is attached. The sphere B has a hole along its diameter through which a rod passes. The spring as well as the sphere B slide freely along the rod. The rod with spring is fixed horizontally as shown in Fig. 1.2.

Apply the force F and compress the spring (Fig. 1.2*A*.). The new position of the sphere will be B_1 as shown in Fig. 1.2*B*. Now release the sphere. It comes to the position of equilibrium B_2 (Fig. 1.2*C*.). Then it moves on the other side upto the position B_3 (Fig. 1.2*D*.). Finally it returns through the position B_4 (Fig. 1.2*E*.) to the position B_5 (Fig. 1.2*F*) which is same as the starting position B_1 (Fig. 1.2*B*.).

As shown in Fig. 1.2*F*, the displacement X at any instant is the distance of the sphere B from its position of equilibrium at that instant. The time required to travel from position B_1 to position B_5 through positions B_2, B_3, B_4 is the periodic time T. Knowing the periodic time T, the number of oscillations per second or frequency can be found using the relation

$$\left[\text{Frequency} = \frac{1}{\text{Time period}}\right]$$

$$f = \frac{1}{T}$$

By the following demonstration the change of displacement with time in the case of a pendulum can be traced.

To the bob of a simple pendulum fix an inked brush. Arrange a glass plate below the bob so that the brush touches its surface lightly. Now move the glass plate with uniform speed horizontally. If the pendulum oscillates, we get a curve, as shown in Fig. 1.3 (*a*).

A portion of this curve is shown in Fig. 1.3 (*b*). This curve shows how the displacement of the simple pendulum changes with time. The displacement is shown on the vertical axis and time on the horizontal axis. When the bob is in position of equilibrium O (see Fig. 1.1), we get the corresponding point O on the curve. In time t_1 the bob

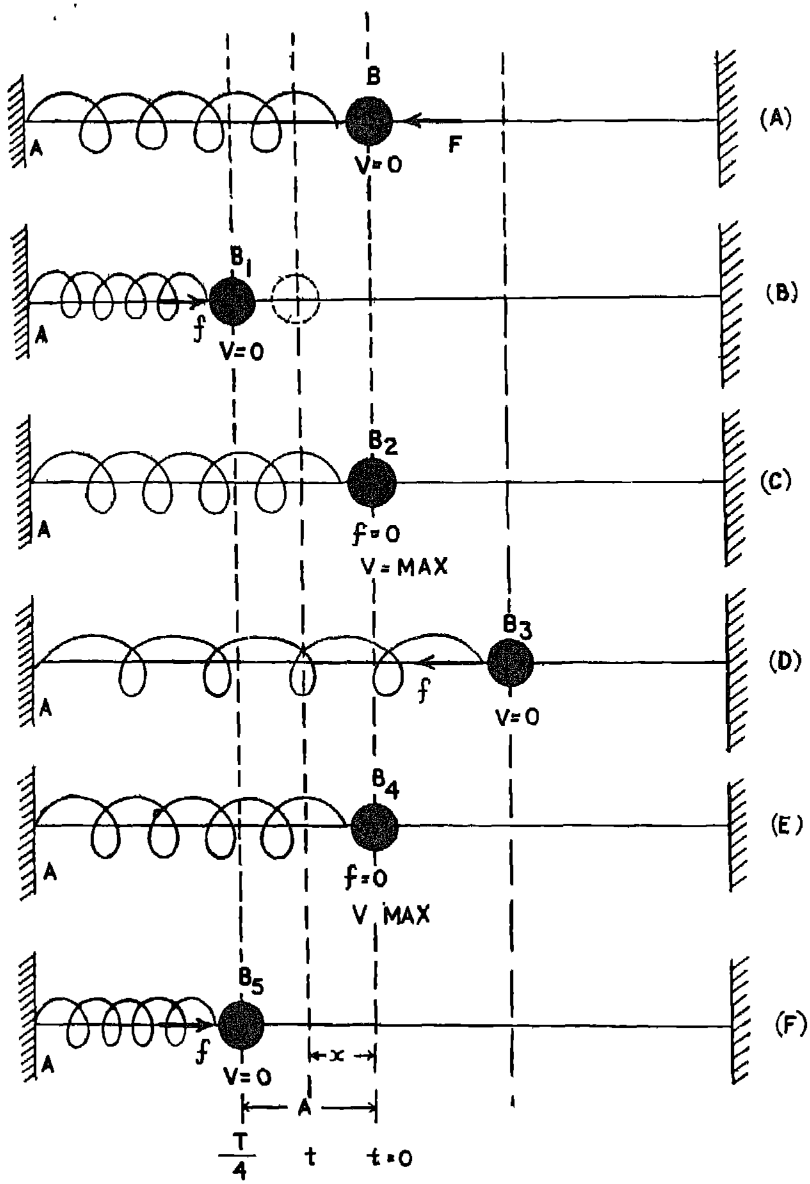


Fig. 1.2. Vibration of a horizontal spring pendulum.

travels a distance x_1 in Fig. 1.1 and corresponding to this we get a point M_1 on this curve. Similarly corresponding to displacement x_2 in time t_2 we obtain the point M_2. At A the displacement is maximum. This

displacement is the amplitude. This bob now returns from A to O and on the curve you obtain points between A and O_1. The points corresponding to motion OBO in Fig. 1.1 are represented by the curve O_1BO_2.

While the bob goes from O to A, back to O and then to B and back to A the curve OAO_1BO_2 is traced and it is a trace of a full oscillation.

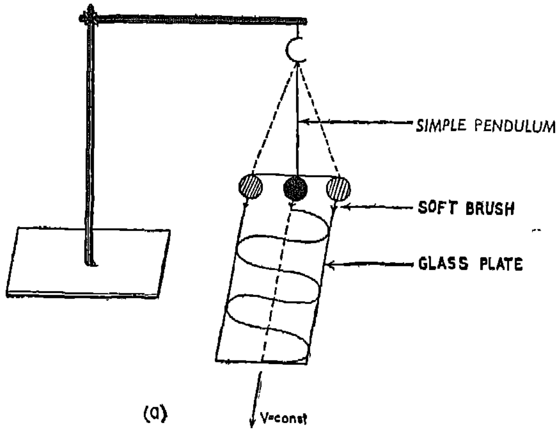


Fig. 1.3 (*a*). Curve traced by an oscillating pendulum.

§ 4. Energy of an Oscillating Simple Pendulum

The motion of a simple pendulum can be explained by taking into consideration the law of conservation and transformation of energy. For the time being let us neglect the friction at the point of suspension. Suppose that the potential energy of the pendulum in position O is zero.

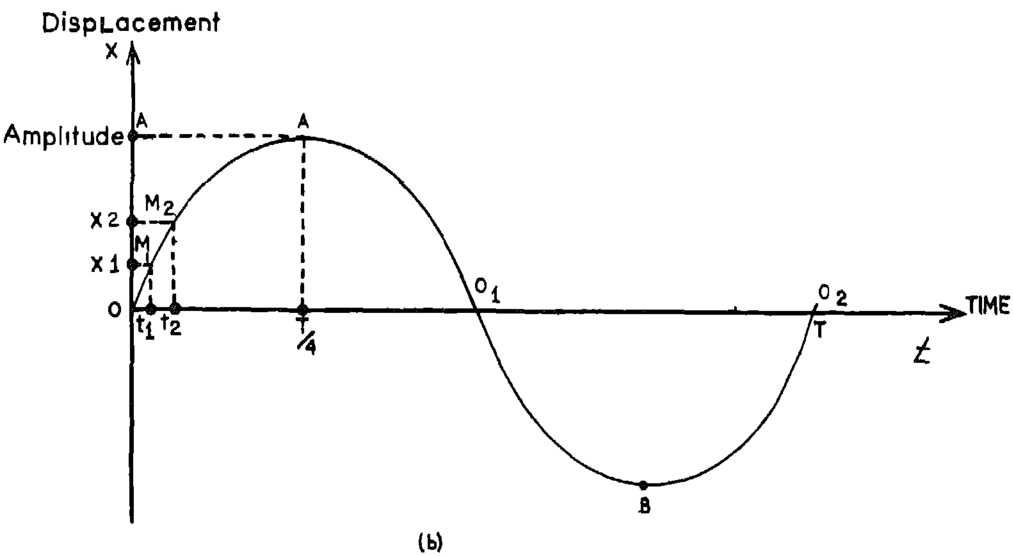


Fig. 1.3. (*b*). A portion of the curve showing the amplitude and time period.

Displace the pendulum from position of equilibrium O to a position A. In doing this some work has to be done against the force of gravity. This is stored in the pendulum in form of potential energy. Thus the potential energy of the pendulum in position A is greater than its potential energy in position O.

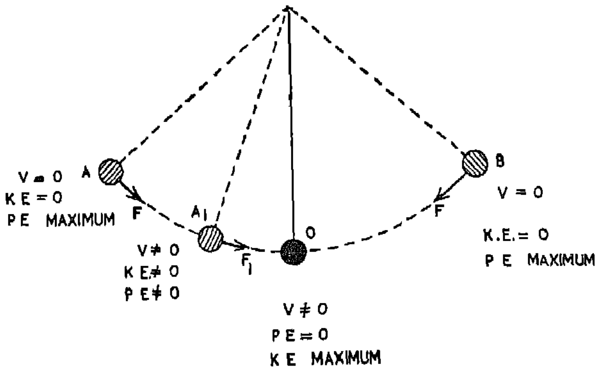


Fig. 1.4. Force acting on an oscillation pendulum.

If the pendulum is now released from rest, it moves towards O. Because the speed of the pendulum is zero at A its kinetic energy is zero at A and it has only potential energy. As the pendulum moves towards O the speed gradually increases, viz., the pendulum starts gaining more and more kinetic energy. At the same time the height of the pendulum gradually decreases so that it loses the potential energy. Then in position A_1 the pendulum has a certain amount of kinetic energy and a certain amount of potential energy. The potential energy in this position is less than that in position A.

The speed of the pendulum gradually increases and attains a maximum at O. At O the pendulum has all its energy in the form of kinetic energy because in this position we suppose that the potential energy is zero. So the whole of the potential energy in position A is transformed into kinetic energy in position O. Since the pendulum has a certain speed towards B, it does not stop at O. When it moves away from O it is gradually doing work against the force of gravity. This gives more and more potential energy to the pendulum. At the same time the speed gradually decreases, when the bob reaches B all of its kinetic energy is transformed into potential energy. The motion form B to A is just repetition of the motion from A to B.

Oscillations due to initial store of energy are called *free oscillations*. The oscillations of a pendulum, which we have explained, are free oscillations. The amount of work done in raising the pendulum from

O to *A* is equal to the initial store of energy. Thus when there is no loss of energy due to friction the amplitude of the oscillation does not decrease. The trace of pendulum obtained by the method described in Section 1.2 is shown in Fig. 5(*a*) when there is no loss due to friction. In nature, however, all oscillating bodies lose energy due to friction. Thus if a pendulum is allowed to oscillate for a long time in air, you will notice that the amplitude gradually decreases and finally the oscillations stop altogether. This is because the energy of the

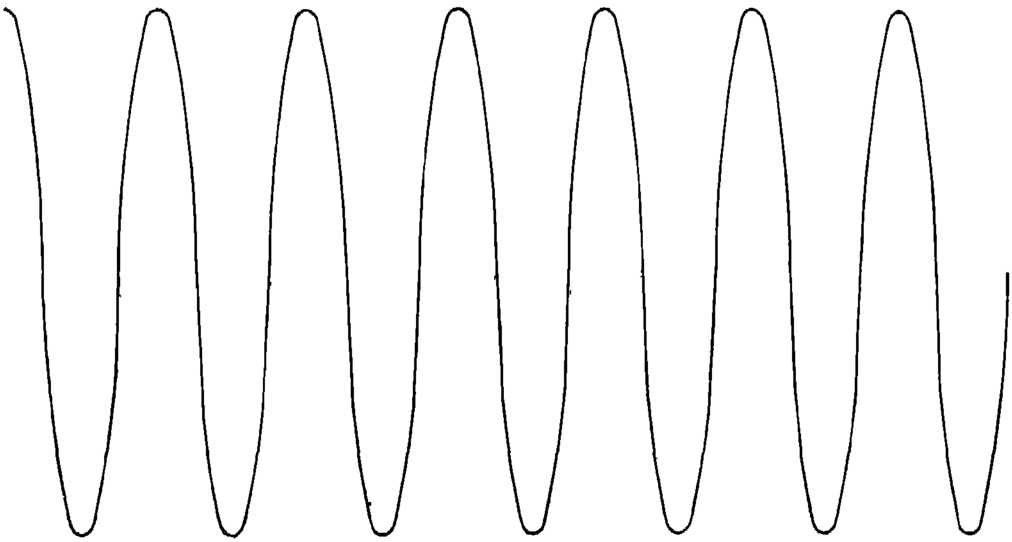


Fig. 1.5 (*a*). Free oscillations.

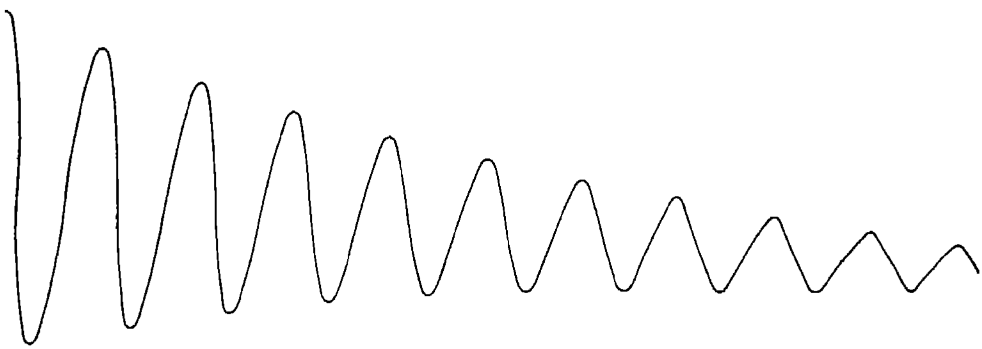


Fig 1.5 (*b*). Damped oscillations of a pendulum in air.

pendulum is spent in overcoming the air-resistance and friction at the suspension. The trace by a pendulum with decreasing amplitude is shown in Fig. 1.5 (*b*). Note how the amplitude decreases gradually. Such type of oscillations are called *damped oscillations* (Fig. 1.5 (*b*)). The greater the resistance which the pendulum has to overcome, the faster its amplitude decreases. For example, you can notice how quickly the oscillations die down, if the pendulum is dipped in water [Fig. 1.5 (*c*)].

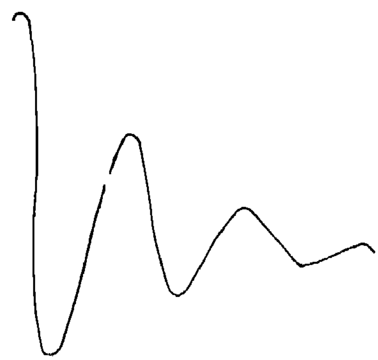


Fig. 1.5 (*c*). Damped oscillations of a pendulum when dipped in water.

EXERCISE 1

1. Find the frequency and the periodic time of oscillation of a pendulum which makes three complete oscillations in one second.
2. How many times is the potential energy transformed into kinetic energy and the kinetic energy back into potential energy during one complete oscillation of a pendulum ?
3. Make a simple pendulum at home and note the number of oscillations it makes in air and in water before its amplitude becomes almost zero. The initial amplitude of oscillation should be the same in both the cases Change the lengths of the pendulum and repeat the experiment in air. How does the periodic time depend on the length of the pendulum ? Make a brief summary of the experiments.

§ 5. Vibrating Bodies Produce Sound

The world in which we live is full of sound. For instance all of you are familiar with the singing of birds, the broadcast on a radio, the songs and dialogues in a movie, the horn of an automobile etc. Our speech with which we communicate with each other is in fact also a train of sounds. Thus sound plays a very important role in our life.

What is the source of sound? Let us answer this question in this section.

A *tuning fork* is shown in Fig. 1.6.

It is made of a metal and resembles the shape of the capital letter *U*. By means of the handle it is usually mounted on a wooden box. The straight portions or limbs of the tuning fork are called *prongs*. In the study of sound a tuning fork is often used as the source of sound.

Strike lightly one of the prongs with a hammer having a rubber padding. Bring your ear close to the prongs. Do you hear the sound? Yes. Now suspend a small ball (say, a bead) by a thread from a stand. (Fig.1.6.) Bring it near the

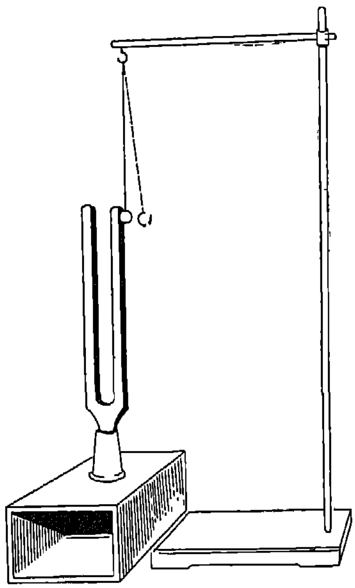


Fig. 1.6. A tuning fork pushes away a light ball.

edge of a prong. Do you see the motion of the ball? The prong of the tuning fork strikes the ball repeatedly. In other words it oscillates or vibrates. Now touch the prong lightly by a finger. The motion of the ball stops. The sound also stops simultaneously. Now you do not hear any sound from the fork. This means when the prongs are vibrating, sound is produced and when the prongs stop vibrating, sound also stops. Thus a vibrating tuning fork produces sound.

As a second example of a sounding body let us consider a sonometer. A sonometer, as shown in Fig. 1.7,

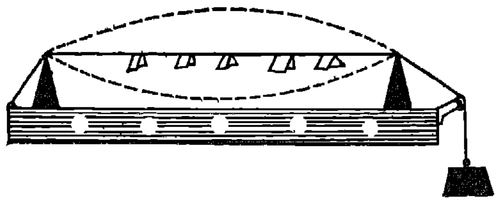


Fig. 1.7 Vibration of a string in a sonometer.

consists of a wooden box. A wire is held tight between two fixed supports above the surface of the box. The tension in the wire may be changed by winding it on the supports. As shown in the figure keep 4 or 5 pieces of light paper on the wire. Now pluck the wire slightly at the centre. You can now hear sound and the pieces of paper start moving vigorously and even fall down. This means the wire must be vibrating and the motion is imparted to the pieces of paper. Now touch the wire slightly by a

finger. The pieces of paper no longer move and the sound also stops. This proves that the vibrating wire is a source of sound.

Thus, from the above experiments we may conclude that *all vibrating bodies produce sound.*

§ 6. Propagation of Sound

If we wish to hear sound, first of all it must be produced. From the previous section we know that all vibrating bodies are sources of sound. The second condition is to have a detector of sound. It is usually the human ear. The third condition is a medium between the source and detector of sound. Let us perform the following experiment to show that the sound cannot travel from the source to another place without a material medium.

Place a clock upon a thick piece of rubber and cover it by a glass bell jar (Fig. 1.8). You can hear well

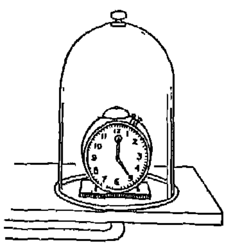


Fig. 1.8. A clock is placed inside a bell jar connected to an air pump and air is taken out.

the sound from the clock. Now start pumping the air out of the bell jar. Do you notice any change in the loudness of the sound from the clock? As the air under the bell jar becomes more and more rarefied, the sound becomes weaker and weaker. If all the air is removed from the bell jar, sound stops altogether. At the same time notice that the hammer continues vibrating as initially. We do not hear sound because there is no medium in the jar for the sound to travel.

Stop pumping out the air. Outside air gradually leaks into the bell jar. Simultaneously, note that the sound becomes gradually louder. Thus the sound reaches our ear only through the air. *Sound cannot travel in vacuum.*

Why is it that a material is necessary for propagation of sound? To answer this question fix tightly a hacksaw blade at one end of it in a vice. (Fig. 1.9). Pull its free end through some distance and release it. The blade starts vibrating and you hear a sound.

The layers of air are shown in Fig. 1.9 (*a*) when the blade is initially in the position of equilibrium. Note that the layers of air are uniformly distributed. When the blade moves to the extreme right position [Fig. 1.9 (*b*)], it pushes the air

layer in front of it. The air in front of the blade is now compressed. This region is called a *compression*. When the blade goes back, the air in front of it becomes rarefied. This region is called a *rarefaction*. The pairs of compression and rarefaction travel in air. In physics this is called sound waves. The sound waves formation, when the blade oscillates for some time, is shown in Fig. 1.9 (*d*). The waves produced by the vibrating bell can be seen in Fig. 1.9 (*e*). The propagation of waves can also be shown with the help of a spring. Fig. 1.10 shows a long spiral spring suspended horizontally. Strike the free end of the spring rhythmically with your hand. The coils at the end of the spring compress at each stroke of the hand. Thus a compression is formed. Remove the hand from the spring. The coils separate from each other. Now a rarefaction takes place. The coils of the spring start oscillating. These oscillations are conveyed from coil to coil along the

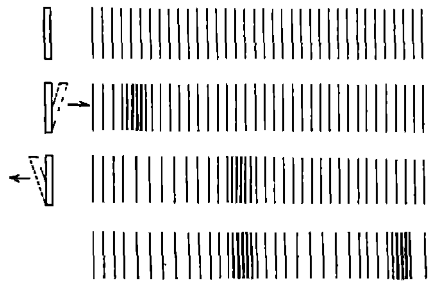


Fig 1.9 (*a*). A blade is fixed tightly so that it can be made to vibrate. It shows that the molecules of air are in equilibrium.

Fig. 1.9 (*b*) The motion of the blade when it occupies the extreme right position.

Fig. 1.9 (*c*). Oscillations of the blade when it moves backward.

Fig. 1.9 (*d*). The blade oscillating for some time.

Fig. 1.9 (*e*). Sound waves from a bell.

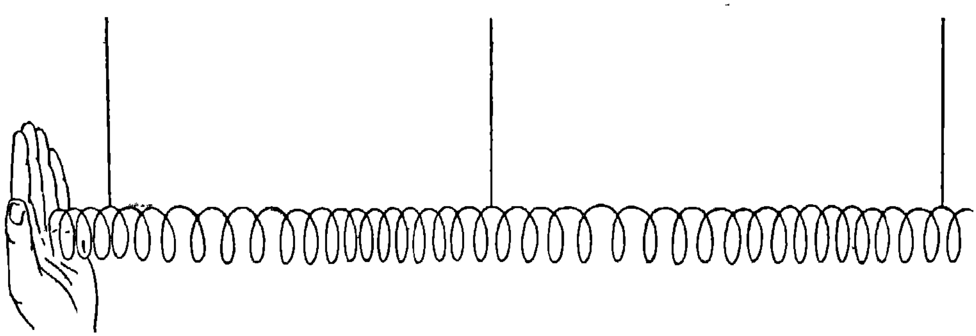


Fig. 1.10. Wave motion in a spring.

length of the spring due to interactions between coils.

Similarly, *the compressions and rarefactions produced in the air are handed over from one layer to the next due to interactions between them and sound travels in the material medium.*

We shall discuss below how the speed of sound is measured.

Let us denote the distance between the source and detector of sound by S. Note the time when the sound is produced at the source and when it reaches the detector. Let us denote this time interval by t. Then

$$\boxed{\text{Speed of sound} = \frac{\text{Distance between the source and detector of sound}}{\text{Time required to travel this distance}}}$$

Denote the speed of sound by V. Then with the above notation,

$$\boxed{V = \frac{S}{t}.}$$

Sound travels not only in gases but in liquids and solids too.

The sound is transmitted over greater distances through the railway tracks. Put your ear in contact with the track or ground and you can hear the sound of an approaching train or the clatter of the hooves of a horse.

The speeds of sound in various media are given in table 1.

Table 1.

Medium	*Speed in metres/sec*
Air	345
Saturated water vapour	400 approx
Water	1498
Mercury	1448
Copper	3700 approx
Steel	5000 to 6000
Glass	5000 approx
Wood	4000 to 5000
Cork	550 approx
Rubber	30 to 70

EXERCISE 2

1. During a thunderstorm the thunder is heard 0.8 s. after the flash is seen. If the speed of sound is 345 m/s and if the light travels very fast compared to the sound, calculate the distance at which the lightning has taken place.

2. The distance between the observer and a locomotive is 517.5 metres. If the locomotive sounds the whistle, find the time lag between hearing the sound and seeing the puff of the white smoke from the locomotive.

3. A and B are two observers. The observer A strikes a bell under water and simultaneously ignites some gunpowder. The distance between the two observers is 3.75 km. The observer B starts a stop watch as soon as he sees the flash of the gunpowder. The sound of the bell travelling under the water uniformly, is received by B after 2 5 s. What is the speed of sound in water ?

4. A bell was struck at one end of a metal bar 1085 metres long. The observer at the other end heard the sound through the bar. After 2.75 s. he heard the sound again—this time through air. If the speed of sound in the air is 345 m/s, determine the speed of sound in the metal.

5. Fasten a string or wire at least 25 metres long through holes in the bottom of two tin cans. Knot the ends to prevent it from slipping. Speak through one of the cans with your friend at the other end of the stretched string. Why do you hear each other better with this toy telephone than without it ?

§ 7. Characteristics of Sound

The sounds produced by various vibrating bodies, by the human voice and by the various musical instruments are distinguished from each other by *loudness and pitch.*

To understand the first characteristic of sound, namely loudness, let us perform a simple experiment. Suspend a light ball by a thread from a stand so that the ball just touches the end of a prong of the tuning fork (Fig. 1.6). Strike the tuning fork by the hammer lightly. Hear the sound and note the maximum distance through which the ball is displaced from the tuning fork. Touch by a finger the prongs to stop the vibrations of the tuning fork. Now again strike the tuning fork but this time with a larger force. Hear the sound and note the maximum displacement of the ball.

Now let us compare the results of the above experiment. Have you noted that the sound was louder in the second case than in the first ? In the second case the displacement of the ball was larger than in the first case. From this we conclude that the loudness of sound depends upon the amplitude of oscillations of the source of sound.

To explain the second characteristic of sound, namely pitch, let us perform another experiment. Arrange two tuning forks of different lengths and attach a light ball to each, as in the previous experiment. Then strike the first tuning fork with a certain force and hear the sound. Simultaneously note

the maximum displacement of the ball in the first moment of its oscillations. Then strike the second fork with nearly the same force and hear the sound. Observe that the maximum displacement of the ball is nearly the same as in the first case. But still the sounds of the two tuning forks are not exactly same. The sounds from the two tuning forks are said to differ in pitch.

To understand on what the pitch of sound depends, perform the following experiment. In Fig. 1.11, a

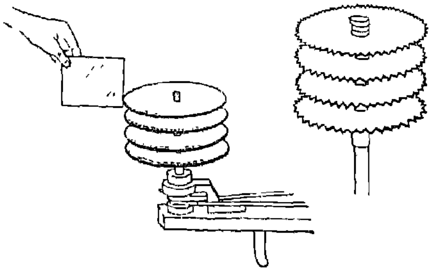


Fig. 1.11. A device showing the dependence between the sound pitch and frequency.

device consisting of several ratcheted metal discs fitted on a common shaft is shown. The number of teeth on the discs is different. Rotate the device uniformly by a centrifuge machine. Touch the teeth of the lowest disc with a piece of thin cardboard. Do you hear the sound produced by the vibrating piece of cardboard? Without changing the speed of rotation touch the other discs one after another. You hear different sounds of same loudness but of different pitch. The frequency of oscillations of the cardboard depends on the number of teeth of the discs. So we can conclude that the pitch of the sound depends on the frequency of the source of sound.

Human ear responds to sounds of frequencies between 20 and 20,000 cycles per second. When you wave your hands back and forth, they are vibrating, in a way. However, no sound is heard because the vibrations are not fast enough. The sounds of human voice lie between the range of .60 c/s (lower bass note) and 1,300 c/s (upper soprano note).

As he frequency increases above 20,000 per second the sound becomes *ultrasonic*. We can no longer hear the sound, but there are vibrations in the air Some animals, for instance dogs, bats respond to ultrasonic sound. The bats are known to generate and receive ultrasonic frequencies which help them to take bearings during flight.

Sounds of ultrasonic frequencies find many applications in modern life. They are used to detect flaws in metal castings, to clean clothes, to wash dishes, to cut hard materials, to solder aluminium etc. Sounds of ultrasonic frequencies produce biological effects too. For instance,

irradiation of grain by it increases the crop yield. Milk irradiated by ultrasonic frequencies will not turn sour for a long time. The nautical uses of ultrasonics are discussed below (see Section 8).

§ 8. Reflection and Absorption of Sound

To understand the specific features of the propagation of sound waves let us perform the following experiment. Keep a watch at the bottom of a glass cylinder as shown in Fig. 1.12. You cannot hear the sound very clearly. Now hold a plane wooden sheet as shown in the figure. Now you can hear the sound better. What is the reason? The sound starts from the watch and reaches the plate. At the plate, the direction of the sound waves changes and we hear the sound. This is one of the specific features of sound waves and is called *reflection of sound.*

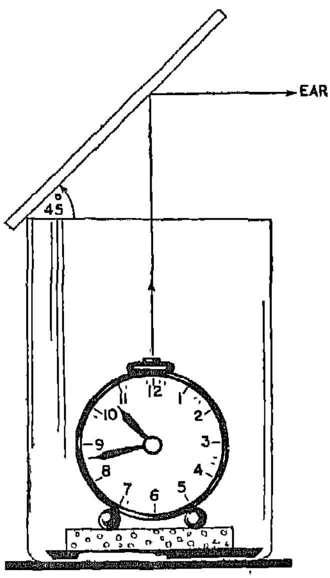


Fig. 1.12. Reflection of sound when a clock is placed at the bottom of a glass cylinder.

Let us now study how reflection of sound waves depends upon the nature of reflecting material. This is done by using different bodies as reflectors keeping the source same and by hearing the sound. Experimentally, it is found that metallic sheets, wooden plates, plywood etc., are good reflectors of sound. On the other hand clothing, porous material, cork etc., are bad reflectors.

One particularly interesting phenomenon that takes place due to reflection is called *echo*. Echo exists when we can hear separately the original and reflected sounds. We can hear two sounds separately only if they arrive to us with a minimum time lag of 1/15 sec. This is a specific feature of the human ear. Knowing this fact and the speed of sound in the medium concerned, the minimum distance between the human ear and the reflector to produce an echo can be calculated.

Thus, since the speed of sound in air is 345 m/s the distance travelled

by sound in this period should be $345\ m/s \times \frac{1}{15}\ s = 23$ metres. This means that the human ear can detect an echo only if the distance between the source of sound and the reflecting surface is 11.5 metres and more. This usually happens in hills, deep wells or dens.

When the distance between the source and reflector of sound is less than 11.5 metres, the original and the reflected sound mix up. Thus instead of a short "oh" we shall hear the protracted "Oooh". In closed space the sound reflected from the walls, ceiling, floor and other objects in the room mix up with the original sound and the speech becomes blurred.

Auditoriums are now built with rounded corners and few flat surfaces. This prevents sound waves from being reflected to any one position. They are spread in many directions and the only sounds heard are those sent out from the source. The walls, ceiling and floor of a good auditorium are covered by appropriate amount of sound absorbing material. The clothes worn by the audience also absorb sound. Thus waves are either scattered or absorbed so there is very little reflection.

The reflection of sound has found application in depth-sounder, a device for measuring ocean depths. A short sound signal sent from the ship towards the bottom of sea returns to the ship after being reflected from the bottom. Knowing the speed of sound in sea water and the time required to cover the distance from the ship to the bottom and back, we can determine the depth. Modern depth-sounders use ultrasonic frequencies. Sonar, which is a coined word from Sound Navigation and Ranging, is used to locate submarines and large shoals of fish.

§ 9. Resonance of Mechanical Oscillations

You have already studied the oscillatory motion of a simple pendulum and a horizontal spring pendulum. Both of these execute free oscillations. We often come across another type of oscillations. For example, suspend a simple pendulum and push it by hand at regular intervals. Now the oscillations of the pendulum are called *forced oscillations.*

Suspend from a stand pendulums as shown in Fig. 1.13*a*. Displace and release the pendulum *A* so that it starts oscillating. Soon you can observe that the other three pendulums also start oscillating. Note that in the earlier experiment the

periodic force which induces the forced oscillations, was supplied by the hand In this experiment it is supplied by the periodic motion of the simple pendulum A.

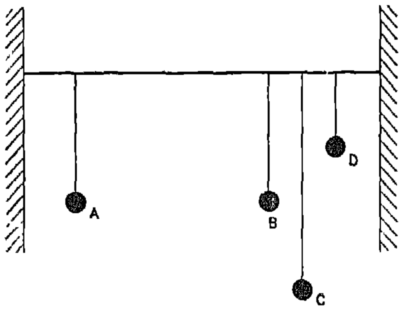


Fig 1.13(a). Four pendulums to show resonance.

Now observe the pendulums B, C and D. You will find that they start oscillating and the amplitude of B is the maximum. As shown in the figure the lengths of A and B are equal. Since the frequency of a simple pendulum depends on its length, the pendulums A and B have same frequency. This particular phenomenon of forced oscillations when the frequency of oscillating force (from pendulum A) is equal to the natural frequency of the oscillating body (pendulum B which has the same length as pendulum A) is called the *resonance*.

Resonance is a very important phenomenon in nature and practice. Large number of bodies, different parts of machines, various types of constructions etc., execute forced oscillations. In engineering and technology resonance is advantageous as well as dangerous. It is a historical fact that a bridge on the river Seine in Paris was broken down by the action of the periodic force when the troops were marching over the bridge. Similar disasters may be caused by the periodic action of the wind. Resonance finds useful applications in the study of sound and radio.

§ 10. Resonance of Sound

Let us study the resonance of sound. For this purpose, perform the following experiment.

Arrange four tuning forks on a table as shown in the Fig. 1.13b so that one is separated from the other three. The tuning forks A and B are of the same length and hence of the same frequency. The tuning forks C and D differ in frequency from each other and from A and B.

Strike the tuning fork A by a hammer and note that it produces sound of a certain pitch. This sound is produced by free oscillations of the tuning fork A. Next stop the vibrations of tuning fork A

When the tuning fork A was vibrating it produced sound waves in air They reached the tuning

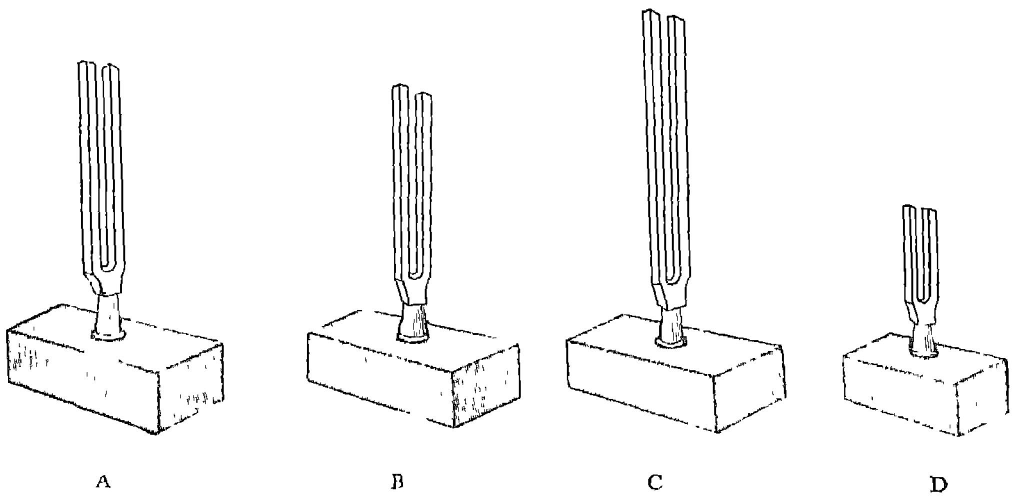


Fig. 1.13(*b*). Four tuning forks arranged to show resonance.

forks *B*, *C* and *D* and due to their periodic action these tuning forks are now vibrating. Hear the sound produced by tuning forks *B*, *C* and *D*. The sound that you hear is produced by forced oscillations of these three tuning forks. Compare the sound produced by each of the three tuning forks *B*, *C* and *D*. You can draw the following conclusions :

(*i*) All the three tuning forks produce sound of the same pitch as the sound produced by the tuning fork *A*.

(*ii*) The sound produced by the tuning fork *B*, which has the same frequency as the tuning fork *A*, is louder than that produced by other two tuning forks.

This experiment is analogous to that described in the Section 11 and this phenomenon is called *resonance of sound*. The bodies which respond to this type of forced vibrations are called *resonators*. The tuning fork *B* in the above experiment acts as a resonator.

If we hold a vibrating tuning fork by its handle we hear a sound of a certain loudness. Now touch the table top by the handle of the tuning fork. Observe that the sound becomes louder. The sound becomes louder because the table also starts vibrating with the same frequency as that of the tuning fork. This is why usually the tuning forks are mounted on hollow wooden boxes which act as resonators.

Resonators of different shape and construction are used in different musical instruments, viz., piano, sitar, tambura etc.

The vocal chords are the source of voice in man and many animals. Vibrating under the action of an air stream coming from the lungs they produce weak sounds. Passing through the resonators—the larynx and mouth cavity—these sounds are intensified.

11. Principles of Recording and Reproducing Sound

Sound was recorded and reproduced for the first time by Edison in U S.A. (1877) Many of you may be familiar with the gramophone or radiogram.

The grooves seen on the surface of a record through a magnifying glass are part of the spiral groove which starts at the edge and runs to the centre (Fig 1.14.) This groove is called track of sound. Fig. 1.15 gives a simple diagram of a mechanical sound recorder. The membrane *M*, which is made of a flexible material, is coupled with lever *A* which has a cutter at its tip. *D* is a disc, coated with a sufficiently soft material.

From the source of sound the sound waves are directed through the horn *H* to the membrane *M* which begins to vibrate with the same frequency as the frequency of the sound waves. The vibrations of the membrane are transmitted to the cutter

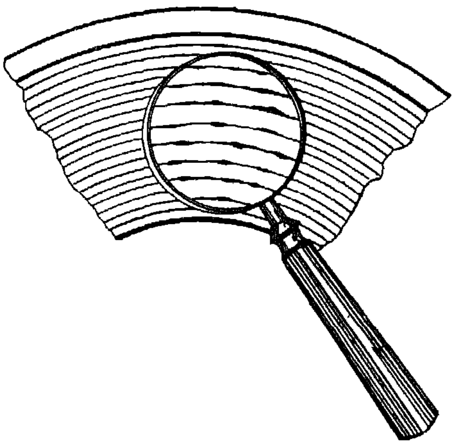
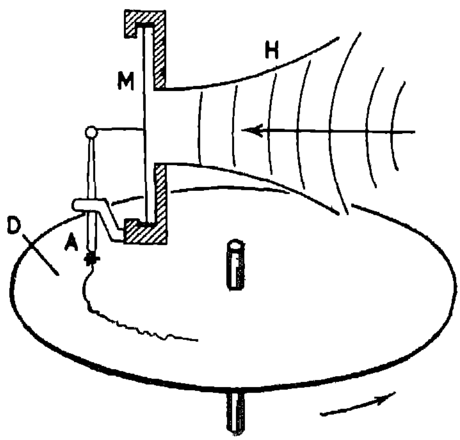


Fig. 1.14. Sound track of a record,



Fig, 1.15 Diagram of a mechanical sound recording.

A which vibrates and cuts the track of sound in the soft material of the rotating disc. A metal copy is made from this disc which is then used for stamping gramophone discs.

A device for sound reproduction is similar in design to that used in recording sound. The only difference is that the cutter is replaced by a needle. When the needle coupled with the membrane is placed at the beginning of the groove and the disc is rotated, the needle sliding along the groove will set the membrane vibrating. The membrane reproduces sound waves and we hear the recorded sound.

In addition to mechanical recorders there are other types of sound recorders based on various physical phenomena, for example, tape recorders.

EXERCISE 3

1. The speeds of rotation of two turbines are 3000 revolutions/minute and 1500 revolutions/minute When working, which of the two will produce a sound of higher pitch ?
2. It is known that the bees returning to the bee-hive, after collecting the honey, flap their wings about 300 times per second and when without honey about 440 times per second. From simply the hum of the bees experienced beekeepers recognise if the bees are going for honey or returning to the bee hive. Explain how.
3. Classify the following into free or forced oscillations. Up and down motion of the needle of a sewing machine, the motion of a simple pendulum in vacuum and in water; the motion of the spring in Fig. 1.10.
4. When carrying two buckets by means of yoke, at a certain speed of walking, the buckets start a vigorous up and down motion How will you explain this ?
5. An observer is 423 metres from a cliff How many seconds will pass before he hears the echo of his voice? (Given that speed of sound is 345 m/s)
6. A sound signal is sent from a boat and after 0 8s it is received again on reflection from the bottom of the sea. If the uniform speed of sound in the sea water is 1500 m/s, calculate the depth of the sea
7. Explain why the words spoken in a horn (megaphone) are heard better over considerable distances compared to words spoken without the horn. (See Fig 1.16)

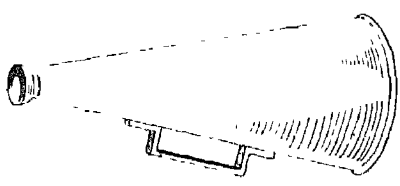


Fig 1 16.

CHAPTER II

Light

§ 12. Sources of Light

In this chapter we will study one of the most important phenomena in nature, namely, light. Our knowledge about the behaviour of light has been applied in various branches of science, namely physics, chemistry, biology, engineering, medicine etc.

The sun is the main natural source of light. A large number of artificial sources of light are also in use, viz., fire, woodsticks, oil lamps, candles, gas lamps, electric bulbs etc. In these sources of light, the light is given out by flames or heated metal filaments. Thus, mankind has been making use of hot sources of light up to our times.

In nature, however, we come across the so called 'cold light', for example, the light of the fire-flies. In this case the bodies giving out light are not red hot. At present various gas-filled electrically operated tubes and bulbs are in use. The light emitted by them resembles day-light.

It is easily observed that the light emitted by all the sources is not equally strong. Thus a room can be lighted far better by a tube light than by a candle. The intensity of the light also depends upon the distance from the source of the light.

All sources of light have definite dimensions. However, if the dimensions of the glowing body are very small compared to the distance at which we are observing its effect, any usual source of light can be looked upon as a point source. Thus a glowing sphere, 1 cm in diameter, appears like a glowing spot from a distance of 30-35 metres. Similarly huge stars, many times bigger than the sun, appear to us point sources of light since their distance from earth is really very large.

§ 13. Light Travels in Straight Lines

Set up three cardboards about 10 cm square and a candle flame, as in Fig. 2.1. Arrange the cardboards so that you can see the candel

flame through the holes. Pass a straight rod through these holes and note that in this position all the holes lie in a straight line. Move

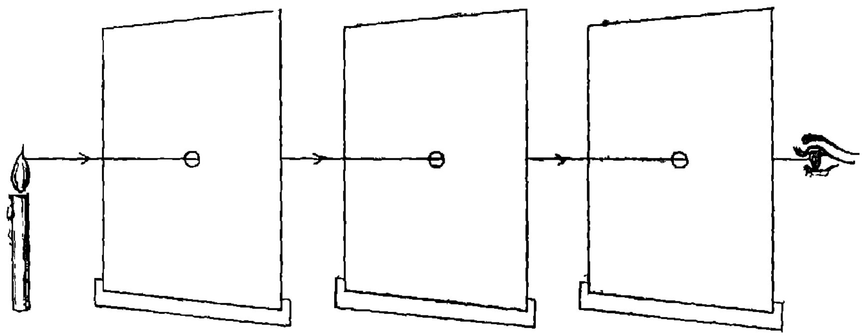


Fig 2.1. A set of cardboards arranged in a line to see the candle flame

one cardboard slightly toward either side. Can you see the candle flame now ? No. This is because the light from the candle travels only in a straight line.

The path of light can be observed in a darkened room or a cinema house. The light illuminates the dust particles in air on its way. The illuminated dust particles are in a straight beam (Fig 2.2). This shows that light propagates in a straight line. A single line along the path of light is called a *ray* of light and several such rays form a *beam* of light.

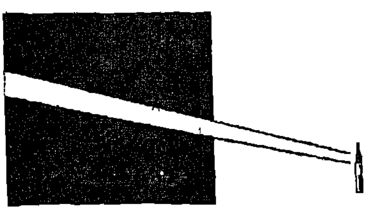


Fig. 2.2. A beam of light in a darkened box filled with smoke.

In ancient times people thought that light propagates instantaneously. But in the second half of the seventeenth century the speed of light was measured experimentally. It is tremendous but still finite. Now we know that the speed of light is 300,000 km/s.

The speed of light is not 300,000 km/sec., in every medium. It is less in air than in vacuum, although the difference is slight. In water it is 1.33 times less than in vacuum and in glass it is approximately 1.5 times less than in vacuum. The medium in which the speed of the light is smaller is called an *optically denser medium*. Consequently glass and water are optically denser media than air.

§ 14. Shadows and Eclipses

If we place a wooden slab or metallic sheet in front of a candle, the light from the candle does not reach us. But the candle can be seen through a glass plate. Objects that do not allow light to pass through them are called *opaque*, while objects that allow light to pass through them are called *transparent*. For instance, wood is opaque but glass is transparent. Some light passes through a ground glass but objects are not seen through it distinctly. Such materials are called *translucent*.

As shown in Fig. 2.3, place an opaque sphere M between the screen

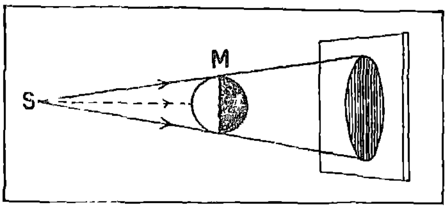


Fig. 2.3 A sphere M between the screen and the point source of light produces shadow.

and the small source of light S. Since light travels in straight lines a patch on the screen remains unilluminated. This dark space is called the *shadow* of the opaque sphere M. Such a shadow can be produced in a dark room by illuminating a sphere with a torch.

Now illuminate the sphere M with two sources as shown in Fig. 2.4. Two shadows AB and CD appear on the screen. They are not as

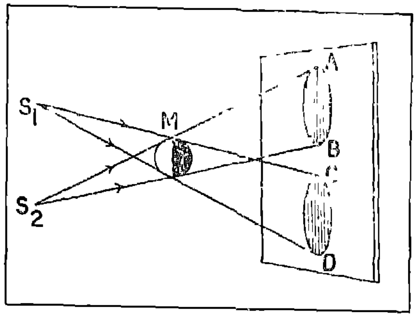


Fig. 2.4. The sphere M is illuminated by two sources and penumbra is formed.

dark as the shadow obtained with one source, because the shadow AB is obtained by source S_2 but receives some light from source S_1 and vice versa. Each of these partly illuminated areas is called a *semi-shadow or penumbra*.

Now gradually bring the two sources near to each other. The semi-shadows also come nearer and nearer and finally overlap each other. This completely darkened part is called a *total shadow or umbra* (Fig. 2.5).

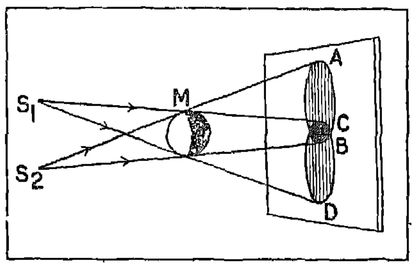


Fig. 2.5. A total shadow or umbra formed by light from two sources.

The diametrically opposite ends of the sun act as the two sources in Fig. 2.5. As the moon revolves around the earth it passes between the sun and the earth at certain times. When this happens, the moon blocks out the light from the sun and casts a shadow on the earth (Fig 2.6).

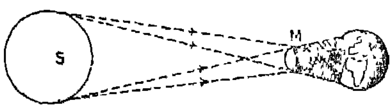


Fig 2.6 A shadow of moon formed on the earth's surface.

Those of us on the earth inside the umbra see a total eclipse; whereas those who are in the penumbra see only a partial eclipse

Similarly the earth passes between the sun and the moon at other times. In this case the moon comes within the shadow of the earth (Fig. 2.7) and we see eclipse of moon.

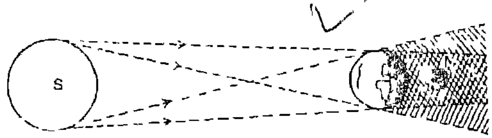


Fig. 2.7 The moon is within the earth's shadow.

Since the motions of the earth and moon have been thoroughly studied, eclipses can be forecasted many years in advance. Astronomers make use of each eclipse for various scientific observations and measurements. Thus, for example, during the total eclipse of sun they have a chance to observe the external portion of the atmosphere of the sun which is ordinarily invisible due to the glare of sun.

EXERCISE 4

1. Place a pencil between the lamp and a sheet of white paper Observe how the shadow of the pencil changes as you move it away from the paper. In what way does the shadow and semi-shadow change in the process? When are the outlines sharp and when are they blurred?
2. How can the heights of objects be compared by their shadows on a sunny day?
3. Why are shadows at noon shorter than in the morning or in the evening?
4. A radio signal was beamed to the Moon in 1946 for the first time It bounced off its surface and was picked up by a receiver on the Earth. What time did it take the signal to get back to the Earth if the distance between the Earth and Moon is 384,000 km? The speed of propagation of radio signals equals that of light.
5. How much time light takes in travelling from the Sun to the Earth if the distance between the Sun and the Earth is equal to 150,000,000 km?

§ 15. Reflection of Light

If we throw a beam of light from a torch on a mirror, we can see a spot of light on the wall This is due to the reflection of light from the mirror.

Let us study reflection from a plane mirror. A special device, known as an optical disc, is shown in Fig. 2.8. A disc is mounted vertically. The circumference of the disc is graduated in degrees, as shown A small piece of plane mirror is fixed horizontally at the centre of this disc. A lamp which can be moved along the circumference of the disc produces a narrow beam of light.

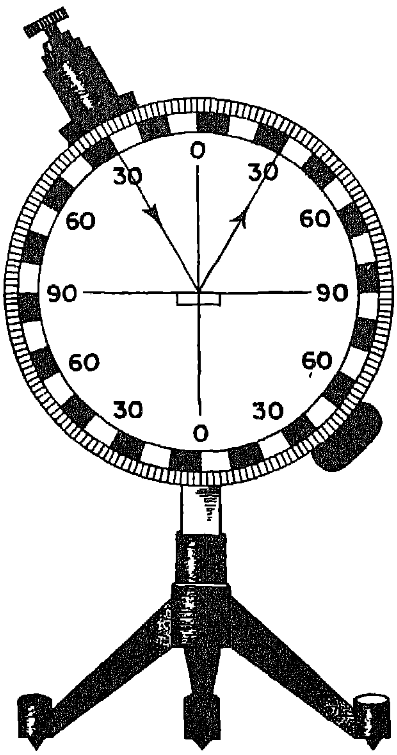


Fig. 2.8. An optical disc. A narrow beam of light falling on the mirror at 30° is reflected also at an angle of 30°.

As shown in the Fig. 2.8, fix the lamp so that the beam of light falls on the plane mirror making an angle of 30° with the normal to the plane mirror Now search for the reflected beam on the other side of the normal. When you see the reflected beam stop moving your eye and mark the direction. You will find that the direction of this reflected beam also makes an angle of 30°, with the normal at the point of incidence. Next change the position of the lamp so that the incident beam makes an angle of 60° with the normal. Find the direction of the reflected beam and read the angle made by this reflected beam with the normal at the point of incidence. Again notice that two angles aret he same. Now allow the light to fall normally on the mirror. The light will be reflected along the direction of the incident light.

Now if you put the lamp at any other angle of incidence, the angle of reflection will always be equal to the angle of incidence.

In Fig. 2.9, let SO be the incident ray starting from the source S and

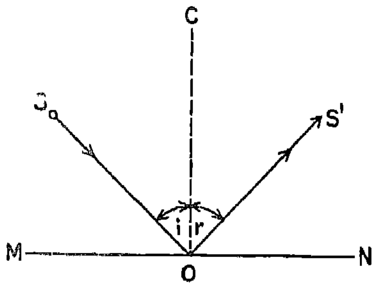


Fig. 2.9. Reflection of light.

falling on the plane mirror MN at O. Let OC be the normal to the plane mirror at the point of incidence O. Then the angle SOC or i is called the *angle of incidence*. If the light travels in the direction OS' after reflection at O, OS' is called the *reflected ray*. The angle $S'OC$ or r is the angle made by the reflected ray OS' with the normal to the reflecting surface at the point of incidence and is called the *angle of reflection*.

Take a sheet of white paper and put it on the mirror so that it contains the incident ray and the normal. You will find that the reflected ray also is in the sheet. If you now twist one side of the sheet so that one half of the sheet contains the incident ray and the normal and the other side is twisted, you will notice that the reflected light is not falling on the sheet. This shows that the incident ray, the normal and the reflected ray are in the same plane.

From the results of the above experiment with an optical disc you must have noted that the incident beam, the normal to the plane mirror and the reflected beam all lie in the plane of the vertical disc D. Also whatever the value of the angle of incidence i, it is always equal to the angle of reflection r. These facts are usually summed up as follows and are known as the *laws of reflection*:

1. The incident ray, the normal at the point of incidence to the reflecting surface and the reflected ray, all lie in one and the same plane.

2. The angle of incidence is always equal to the angle of reflection, *i.e.*, $i=r$.

If the ray strikes the mirror in the direction $S'O$ (Fig. 2.9) it will be reflected in the direction OS. Thus, the incident and the reflected rays are interchangeable.

EXERCISES

1. How will a ray striking the mirror perpendicularly be reflected ?
2. At what angle should a ray fall for the incident and reflected rays (i) to be mutually perpendicular, (ii) to form a 60° angle ?

3. The surface of mirror is horizontal. An incident ray forms a 30° angle with its surface. How should the mirror be turned to send the reflected ray vertically upwards ? What will be the angle between the incident ray and the surface of the mirror in its new position ? Make a drawing to clarify your answer.

4. The angle between mirror and incident ray is equal to 30°. What would be the value of angle of reflection ?

5. The angle between mirror and incident ray is equal to 25° What will be the sum of the angles of incidence and reflection ?

6. The angle of incidence increases by 30°. How much the angle of reflection will increase ?

§ 16. Regular and Diffused Reflection

If you stand in front of a mirror, you can see your reflection, but not, if you stand in front of a wall What makes the difference?

The surface of a wall is obviously far rougher than the surface of a mirror. The magnified view of the surface of a wall is shown in Fig. 2.10. There are a number of pro-

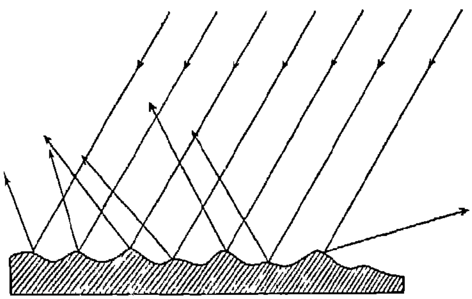


Fig. 2.10. Irregular or diffused reflection.

jections and cavities situated at random. This surface of the wall can be imagined to be divided into a large number of small areas. Each of these small areas can be looked upon as a plane surface, but having their normals in different directions. Thus a *ray* incident on a small plane surface gets reflected in a direction so that the laws of reflection are obeyed and the angle of incidence is equal to the angle of reflection. The same law applies to all other rays and as a result we get the reflected light in all possible directions. This type of reflection is called *diffused reflection.* On the other hand, if a parallel beam of light falls on a plane mirror the reflected rays are also parallel to each other and we get a parallel beam of reflected light (Fig. 2.11). This type of reflection is called *regular reflection.*

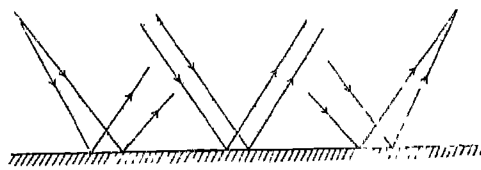


Fig. 2.11. Regular reflection from a plane mirror.

§ 17 Formation of an Image by a Plane Mirror

Let us now explain how an image is formed by a plane mirror. For this, let S be any point on an illuminated object (Fig. 2.12). As

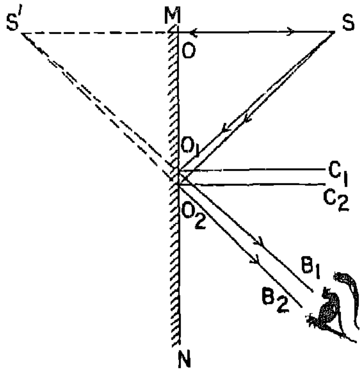


Fig 2.12. Image of a point source of light in a plane mirror

we know the rays of light will be emitted from S in all directions. Consider any two rays SO_1 and SO_2 falling on the mirror at O_1, O_2, respectively. Let O_1C_1 and O_2C_2 be the normals to the surface of the mirror at O_1 and O_2, respectively. Then the ray SO_1 goes in the direction O_1B_1 after reflection such that the angle of incidence SO_1C_1 is equal to the angle of reflection $C_1 O_1B_1$. Similarly the ray SO_2 goes in the direction O_2B_2 after reflection.

Now if we place our eye in front of the reflected rays, we feel that the light is coming in straight lines from a point S'. S' is the point of intersection of the reflected rays when produced backwards and lies behind the mirror. S' is called the image of the point S on the object.

Consider another ray SO starting from the point S on the illuminated object and falling on the mirror perpendicularly. Now the incident ray coincides with the normal and the angle of incidence is zero. The angle of reflection must also be zero. This means the reflected ray also coincides with the normal. The reflected ray OS when produced backwards passes through the point S'.

From the geometry of the triangles SOO_1 and $S'OO_1$ it is easily seen that SO is equal to $S'O$. Physically this means the image is as far behind the plane mirror as the object is in front. Thus the object distance SO is equal to the image distance $S'O$.

Now suppose the object is in form of a triangle ABC. To construct the image of the triangle ABC in the plane mirror MN, drop perpendiculars from the vertices on the triangle ABC to the mirror and produce them beyond the mirror by the same length (Fig. 2.13). The ends of these perpendiculars will be the images of the vertices on the object.

Observe carefully the image

$A'B'C'$ of the triangle ABC in Fig. 2.13. The object and image are not exactly the same. When you are facing the object, the vertex of the triangle lies on your right. But when you are facing the image, the vertex of the triangle lies on your left. This is known as *lateral inversion*. Thus the image of a right hand obtained by reflection in a plane mirror looks like the left hand.

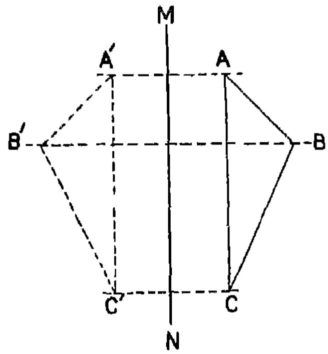


Fig. 2.13. Lateral inversion in a plane mirror

From the above discussion the following is clear about an image obtained by a plane mirror.

1. The distance of the image from the mirror is equal to the distance of the object from the mirror.

2. The image is formed behind the mirror. The rays of light do not reach the image physically. So it cannot be taken on a screen.

3. The image is erect and of the same size as object but laterally inverted.

This image is called a *virtual image*. From everyday experience we find that the images are formed behind the mirror. Let us find exactly the position of the image by an experiment. Fix a piece of glass vertically to a support Place a lighted candle in front of a glass plate. We can see its image in it (Fig 2.14)

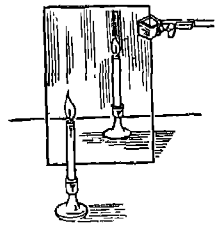


Fig 2.14. Symmetrical position of lighted candle and its image in a plane mirror

Now take another candle identical to the first but unlit and place it behind the plate. Gradually move the second candle away from the plate and find a position in which it will appear as if lighted. This means the unlit candle is in same position where we see the image of the burning candle. Now measure the distances of the two candles from the mirror. They will be equal. Thus, the image of the object in a plane mirror is as far behind the mirror as the object is in front of it.

§ 18. Applications of Plane Mirrors

The plane mirrors find many applications in the modern world. It is known to you that the accuracy of the reading of a scale depends upon the correct position of the eye. To minimise the error in observations, the precision measuring instruments are usually provided with a mirror under the pointer. While reading such an instrument the eye is placed so that the needle covers its reflection in the mirror. (Fig. 2.15).

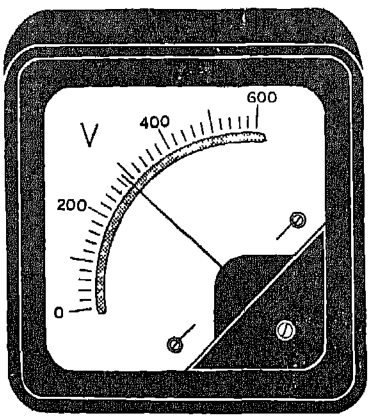


Fig 2.15. An instrument with a mirror which reflects the instrument needle

The periscope

The periscope is an instrument using plane mirrors for looking above barriers or around corners. It consists of a long tube with two plane mirrors at the two ends parallel to each other and inclined exactly at 45° to the axis of the tube. Two other auxiliary tubes at right angles to the main tube (Fig. 2.16) enable

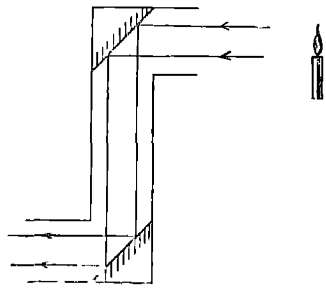


Fig 2.16. A periscope.

a person to look through one of them at an object, the light from which is entering the other tube. Some periscopes have lenses at the observing end of the bent tube to enlarge the image of the object observed.

Periscopes are used by submarines and tank commanders in battle. The officer in the submarine can raise his periscope above the water surface while the submarine is under water. The periscope tube can be rotated about a vertical axis, so that the officer can observe an object lying in any direction. Similarly the tank commander can observe the progress of the battle and give directions to his own tank crews without exposing himself.

§ 19. Laboratory Work No. 1

To study the laws of reflection of light by means of a plane mirror.

Apparatus and materials: A piece of a plane mirror fixed to a block of wood, a ruler, a protractor, four pins, a piece of cardboard or the drawing board, 4-5 thumb pins and a sheet of drawing paper.

Procedure: 1. Fix the drawing paper in the centre of the drawing boards by means of thumb pins.

2. Draw any line MN and place the mirror tied to the wooden block exactly on MN.

3. Fix pins 1 and 2 as shown in Fig. 2.17. Note the reflections

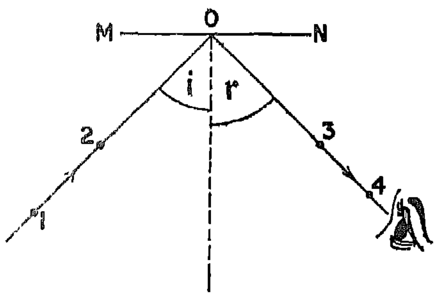


Fig. 2.17. Verification of laws of reflection.

of these pins in the mirror. As far as possible the pins should be vertical.

4. Find a position of your eye so that pins 1 and 2 are seen in one line. Now fix pin 3 vertically so that its lower end and the reflections of the lower ends of pins 1 and 2 appear in one line. Similarly fix pin 4. Now if we look in the direction 4 to 3 we can see only the base of pin 4, and pin 3 and the two reflections of pins 1 and 2 are covered by pin 4.

5. Now remove the pins one by one and mark their positions by a fine pencil. Remove the mirror also.

6. Join the points 1 and 2 and 3 and 4. Produce the lines to intersect in point O (Fig. 2.17). Note that the point O lies on MN.

7. Draw a perpendicular at O to MN. Measure the angles i and r by means of the protractor.

8. Now repeat the experiment with 3 or 4 different positions of pins 1 and 2. Measure corresponding angles (i) and (r) and list them in a table.

Conclusions: 1. The incident ray (line 12), the normal to the plane mirror at the point of incidence O and the reflected ray (line 34) lie in one and the same plane, *i.e.*, in the plane of the paper.

2. From the values of (i) and (r) entered in the table the angle of incidence (i) is equal to the angle of reflection (r) within the limits of experimental error.

EXERCISES

1. Why has the driver of a car, a plane mirror in front of him ?
2. Which paper is better for reading, glossy or dull ? Why ?
3. "Snow sparkles on a sunny day." Explain this phenomenon
4. Usually electric lamps have opaque shades Why ?
5. Why does a piece of glass become translucent if it is rubbed with sand stone ?

§ 20 Spherical Mirrors

Imagine a hollow sphere with centre C. (Fig. 2.18). Cut a por-

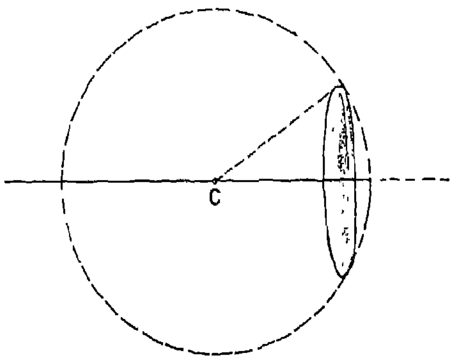


Fig. 2.18 A portion of a hollow sphere cut in the form of a mirror.

tion of it, shown shaded, in Fig. 2.18. Now if the inner surface is polished and light is reflected from it, this portion of the sphere works as a *concave mirror*. On the other hand if the outer surface is polished, this portion of the sphere works as a *convex mirror*. We will consider here only the concave mirror which is often used in practice.

In Fig. 2.19, a section of the concave mirror by a vertical plane is shown. Let us name it AB. The midpoint O of AB is called the

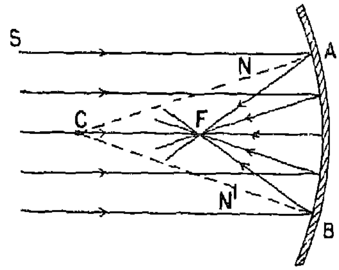


Fig. 2 19 Parallel beam of light reflected from a concave mirror.

vertex of the concave mirror. The centre of the sphere, of which the concave mirror forms a part, is called *the centre of curvature* (C). The line OC, which joins the vertex of the mirror O with the centre of curvature C is called *the principal axis* of the concave mirror.

Let a beam of light, parallel to the principal axis, fall on the concave mirror (Fig. 2.19). Consider the ray SA incident on the mirror at A. The line AC will be a radius at A and will be perpendicular to the small area around A. So the ray gets reflected at A and cuts the

principal axis of F so that the angle of incidence SAC equals the angle of reflection CAF. Similarly all other rays are also reflected from the surface of the concave mirror and pass through the point F. This point F is called *the focus* of the mirror. The distance between the vertex of the mirror, O and the focus F is called the *focal length* of the mirror. The focal length OF of the mirror is equal to half the radius of curvature OC of the mirror. Thus $OF = 1/2\ OC$.

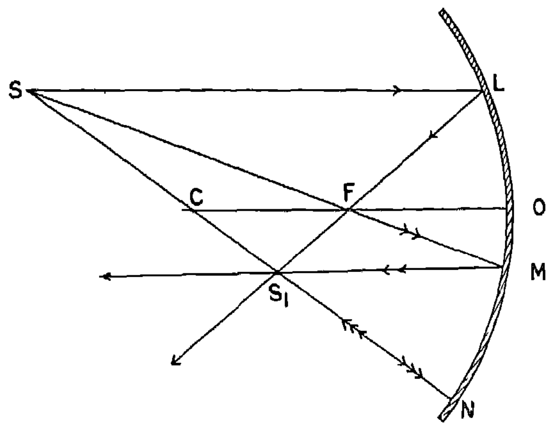


Fig. 2 20. Construction of the image of a point in a concave mirror with two rays, one parallel to the principal axis and the other passing through the focus.

To locate image of a point source of light in a mirror, two rays are sufficient. The point, where they intersect after reflection at the surface of the mirror, gives the position of the image. We know that the rays are given out in all directions by the point source.

Out of them, the directions of the following three rays after reflections are known as explained below.

1. The ray SL, parallel to the principal axis, passes through the focus F after reflection, as discussed above.

2. The ray SM which passes through the focus F must be parallel to the principal axis after reflection. This follows from the fact that the incident ray and the reflected ray are reversible (Fig. 2.6).

3. The ray SN passing through the centre of curvature C gets reflected along the same path The reason is obvious. As we know, the radius CN is the normal to the small area of the mirror around N. Hence the incident ray SCN makes an angle of zero degree with the normal and so the angle of reflection must also be zero, *i.e.*, reflected ray coincides with incident ray.

We use any two of these three rays to construct the ray diagrams in the next section.

§ 21. Applications of Concave Mirrors

We have seen in the previous sections that all rays from a distant

object and parallel to principal axis pass through the focus F after reflection from the surface of a concave mirror. Thus, a beam of sunlight gets concentrated at the focus of a concave mirror and the heat produced is sufficient to burn a piece of cloth or paper.

Since the incident and reflected rays are reversible if a source of light is placed at the focus of a concave mirror, we get a beam of parallel rays (Fig. 2.21). Such a beam of parallel rays is used in a reflector.

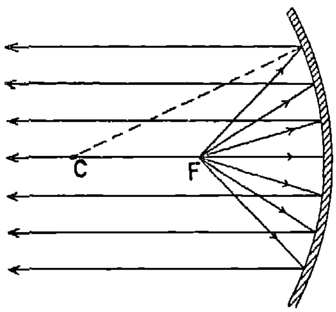


Fig. 2.21. A beam of parallel rays comes out when a source of light is placed at the focus.

A reflector finds applications in projectors, light houses, automobile head lamps, torches etc.

If the source of light is placed between the focus and the vertex of the concave mirror, the reflected beam of light has a tendency to spread (see Fig. 2.22). This beam is usually used in illuminating construction sites, beautiful buildings, monuments and squares etc.

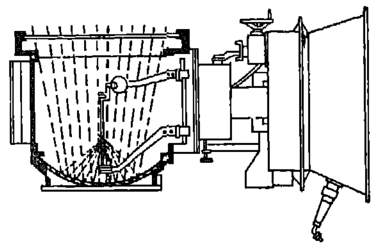


Fig 2.22. A searchlight where a source of light is placed at the focus of a concave mirror.

Huge concave mirrors are used in reflector type telescopes with the help of which scientists observe and study heavenly bodies.

EXERCISES

1. If the sun rays reflected from a concave mirror are focussed on a sheet of paper, the latter will ignite. Why ? Where should the paper be placed in relation to the mirror ?
2. The lamp in a motor-car headlight has two filaments powered independently. The filament of the powerful beam is in the focus of the concave mirror while the one used for parking lights is placed closer to the mirror and somewhat upwards. How do the two beams of light differ from each other ?

§ 22. Refraction of Light

Now let us study another important phenomenon of light, namely, refraction. When a beam of light falls on the surface dividing two transparent media with different optical densities, for example, air and water (Fig. 2.23), part of light is

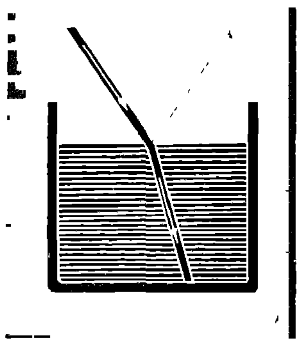


Fig. 2.23 A part of an incident ray is refracted at the surface of separation between air and water.

reflected from the surface and the remaining part passes through the medium. When light passes obliquely from one medium to another, there is always a change in the direction of propagation at the boundary line between the two media. This phenomenon is called the *refraction of light*.

From the point of view of speed of propagation of light, different media are said to have different optical densities. Those in which the speed of light is less are said to be optically denser. When light passes from an optically rarer medium to an optically denser medium, the light bends towards the normal. The idea of optical density is very different from the idea of density of substances which you studied previously.

We frequently come across the refraction of light in our daily life. Thus, a straight rod when partly immersed in water appears to be bent (Fig. 2.24). A coin at the

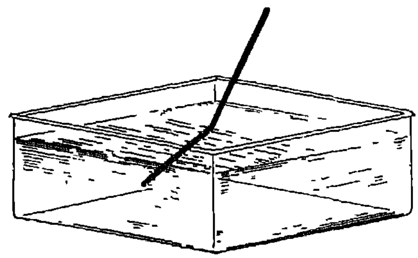


Fig. 2.24. A straight rod when partly immersed in water appears to be bent.

bottom of a cup filled with water appears to be raised up (Fig. 2.25).

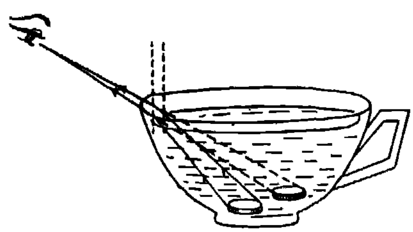


Fig. 2.25. A coin placed at the bottom of a cup filled with water appears to be raised up.

Similarly, because of refraction of light the lakes seem to be shallower than they actually are. In summer sometimes different layers of the atmosphere are heated differently. When light passes from one layer to another it gets refracted and changes its direction considerably. This gives rise to what is known as *mirage*.

Now let us discuss the refraction of light in more detail. In Fig. 2.26,

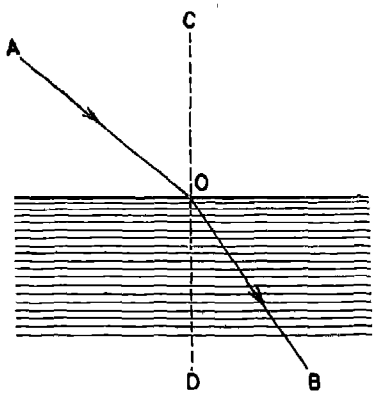


Fig. 2.26. Refraction of light.

let AO be the ray incident at O on the surface dividing the two medii—air and water. Let CD be the normal to this surface at O. Let OB be the refracted ray. Then the angle AOC is the angle of incidence and the angle DOB is the angle of refraction. Note that in this case the angle of refraction is smaller than the angle of incidence.

Thus, in passing from air to water (Fig. 2.26), a ray of light changes its direction and comes nearer to the normal CD. Water is optically denser than air. Hence when light passes from air into water, the angle of refraction is smaller than the angle of incidence.

This is further verified by the experimental ray diagrams shown in Fig. 2.27. Here the ray is incident

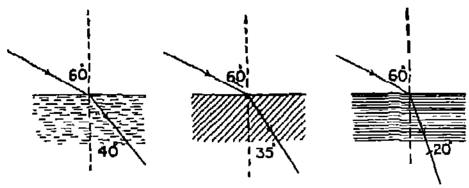


Fig. 2.27. A ray of light passes from air to water, glass and diamond, respectively.

from air on the surface of water, glass and diamond. The angle of incidence is kept fixed (60°). Glass is optically denser than water and the diamond is the densest Hence as we pass from water to diamond, the refracted ray becomes less and less inclined to the normal, *i.e.*, bends more towards the normal.

Let a plane mirror be placed in the path of a refracted ray perpendicular to it. The ray gets reflected from the plane mirror and falls on the surface dividing the glass and air. But since the ray is now passing from an optically denser medium (water) to an optically rarer medium

(air) the ray turns away from the normal and emerges in the direction of the incident ray. Therefore the incident and refracted rays are reversible.

All experiments support the following two regularities regarding refraction of light:

1. The incident ray, the refracted ray and the normal to the surface dividing the two media at the point of incidence lie in one plane.

2. When a ray of light passes from one medium into another with greater optical density, the angle of refraction is smaller than the angle of incidence and vice versa.

§ 23. Refraction through a slab with parallel faces and through a prism

The passage of light through transparent bodies of various shapes, for example, slabs with parallel faces, prisms, lenses etc., finds application in many optical instruments. Let us study here the refraction of light rays through slabs and prisms.

Place a candle in front of a glass slab and view its image through the opposite face (Fig. 2.28). The candle appears to be displaced.

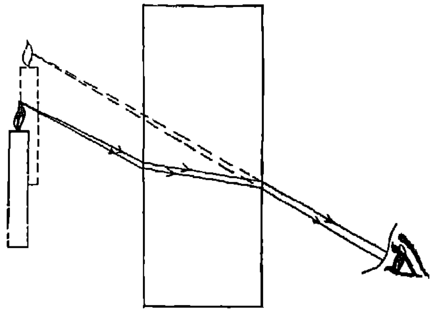


Fig. 2.28. A candle placed in front of a glass slab appears to be displaced.

Let AC be a ray of light incident on the plane surface of the slab at C. Let OCO' be the normal to this surface of the slab (Fig. 2.29). Now the ray of light travels from air to

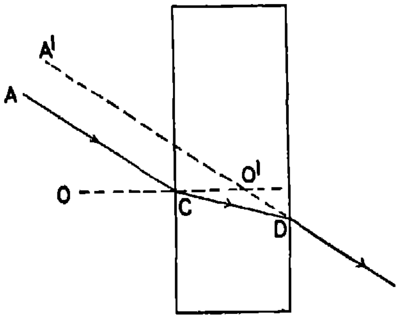


Fig. 2.29. Refraction in a plane parallel to glass slab.

glass, *i.e.*, from an optically rarer to a denser medium. Thus the refracted ray is CD such that $\angle r$, the angle of refraction is smaller than $\angle i$, the angle of incidence. At D the ray emerges from glass into air and deflects away from the normal. Thus after passing through the slab the ray remains parallel to its initial direction but is slightly displaced

laterally. This is why in Fig 2.28, the candle appears to be displaced.

For a given angle of incidence the lateral displacement depends upon the thickness of the slab and the optical density of its material. This displacement increases with the thickness of the slab and the optical density. It also increases with the increase in the angle of incidence. Thus when we see objects through a window pane we do not usually notice any changes in their positions because the glass is thin and the shift of the rays of light passing through the window-pane is hardly noticeable.

Let us now study the propagation of a ray through a prism. Consider a ray *AB* incident on a surface of a prism at *B* (Fig. 2.30). Since the

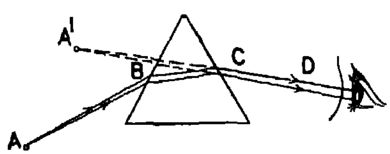


Fig. 2.30. A ray *AB* incident on a surface of a prism at *B*.

light passes from air to glass, as we have seen earlier, the refracted ray bends towards the normal. This ray is refracted again at *C* but now from a denser to a rarer medium, *i.e.*, such that $\angle r_2 > \angle i_2$. It is clear that the ray of light while passing through the prism, is bent twice towards the base of the prism. When viewed through the prism the object appears to be at *A′* and is appreciably displaced.

§ 24. Laboratory Work No. 2

Aim: To study the refraction of light through a glass slab with parallel faces.

Apparatus: A glass slab with parallel faces (or a glass prism), a ruler, a protractor, four pins, a piece of cardboard or a drawing board, 4-5 thumb pins and a sheet of drawing paper.

Procedure: 1. Fix the drawing paper in the centre of the drawing board by means of the thumb pins.

2. Draw any line *MN* and place one edge of the glass slab exactly on *MN*.

3. Fix pins *A* and *A′* on an oblique line *AC* as shown in Fig. 2.29.

4. From the opposite surface find the image of *A* and *B* and fix pins *D* and *E* in line with those images as instructed in step 4 of laboratory work No. 1.

5. Complete the ray diagram as shown in Fig. 2.29 and draw the normals at *C* and *D*.

6. Measure and enter on the ray diagram values of the different angles of incidence and refraction.

7. Repeat the experiment with 3 or 4 different positions of pins *A* and *B*.

8. Measure the displacement of a ray passing through the slab in each case.

Conclusions

1. When passing from an optically rarer to an optically denser medium, the ray of light bends towards the normal and vice versa.

2. The ray of light emerging from a glass slab is parallel to the one entering it.

3. The value of displacement of the ray increases with increase in the value of the angle of incidence.

EXERCISES

1. Under what conditions does a ray of light pass the border line of two transparent media without refraction ?
2. Place a coin at the bottom of a cup so that the cup edge just hides it from the eye. If water is poured into the cup, the coin comes completely into view. Why ? Draw a diagram to explain Fig. 2.25.
3. Place a tea-spoon into a glass filled with water. Take a look at it from above and then from the side. The teaspoon appears as if broken at the surface of water. Why ?

§ 25. Spherical Lenses

Any transparent material polished or moulded with curved surfaces forms a lens. Here we will consider only those lenses the surfaces of which coincide with the surfaces of spheres of equal or unequal radii. Thus the common portion of the two spheres as shown in Fig. 2.31 forms a lens.

The lenses are divided into two classes, *convex* and *concave*, according to their shape. One surface of a lens must be either convex or concave.

Different shapes of lenses are shown in Fig. 2.32.

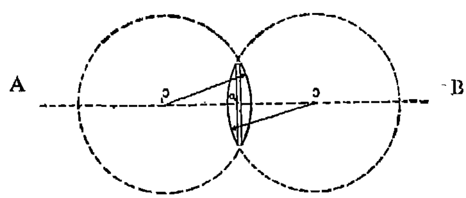


Fig. 2.31. A convex lens having two curved surfaces as part of two spheres.

We will consider in detail only the double convex lens which is often used in practice.

A straight line *AB* passing

through the centres of curvature C and C' (Fig. 2.31) is called the principal *axis* of the lens. The point O is the centre of the lens.

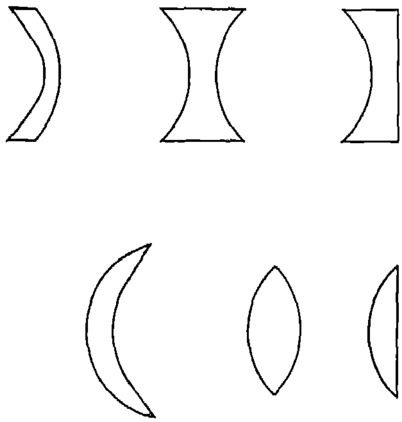


Fig. 2.32. Different types of convex and concave lenses.

Let a beam of light, parallel to the principal axis, fall on a convex lens. (Fig. 2.33). Experimentally

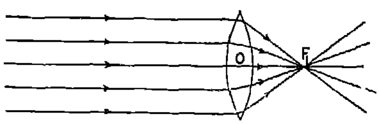


Fig. 2.33. A beam of parallel light falling on a convex lens.

it is found that all these rays pass through a point F_1 after refraction in the lens. This point F_1 is called the focus and its distance from the lens is known as the focal length of the lens. If a beam of light parallel to the principal axis falls on the lens from the other side, all the rays of light will pass through a point F_2 after refraction (see Fig. 2.34). Thus a convex lens has two focii, one on

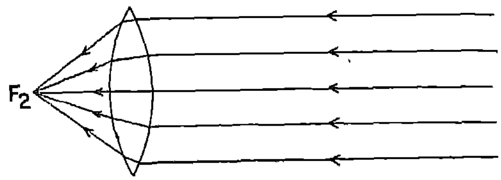


Fig. 2.34. Beam of parallel rays passing through a convex lens converges to the focus.

each side, and hence has two focal lengths. In the case of their lenses, they are equal.

As seen from Fig. 2.33, the convex lens converges a beam of light and is therefore known as a convergent lens (on the other hand a concave lens diverges a beam of light and is known as a divergent lens).

Now let us see why the beam of light concentrates in point F_1 in Fig. 2.33. For this imagine that the lens is divided into a number of pieces as shown in Fig. 2.35. Each of these

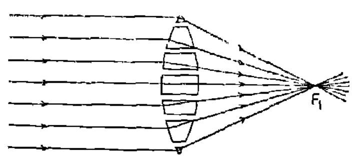


Fig 2.35. Showing the action of convex lens, each portion of the lens behaving as a prism.

sections resembles a prism. Now let us remember that a ray passing

through a prism is bent towards the base. The central ray passing through a slab with parallel faces goes undeviated. The other rays pass through prismatic sections and are bent towards the bases of the prisms, *i.e.*, towards the central part of the lens and pass through the point F_1. For a concave lens the action is just the opposite and the rays are bent away from the principal axis.

Usually the following three rays (Fig. 2.36) whose directions after

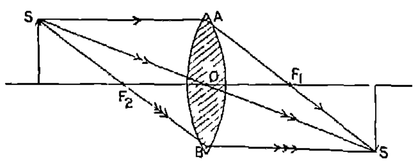


Fig. 2.36. Locating the image formed by a convex lens. Three rays are taken (*i*) ray SA parallel to the principal axis (*ii*) ray SO through the optical centre and (*iii*) ray SF_2 passing through the focus.

refraction through the convex lens are known beforehand, are used when drawing ray diagrams as explained below:

1. The ray SA, parallel to the principal axis, passes through the focus F_1 after refraction as discussed above.

2. The ray SB passing through the focus F_2 must be parallel to the principal axis after refraction. This follows from the fact that the incident and the refracted rays are reversible.

3. The ray SO passing through the centre of the lens goes undeviated.

We use any two of these three rays to construct the ray diagrams in the case of lenses.

§ 26. Images formed by a convex lens

Let us take a candle and put it at a distance greater than twice the focal length from the lens. If we put a screen at a suitable point between $2f$ and f, we will be able to obtain a real image of the candle on the screen. It will be observed that the image is inverted and smaller in size than the candle; Figs. 2.37 and 2.38 also show the construction of the image by drawing the

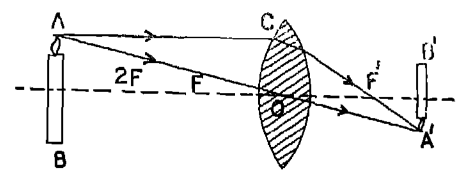


Fig. 2.37. Construction of image formed by convex lens using ray diagrams

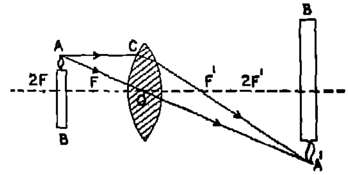


Fig. 2.38. Construction of image formed by a convex lens when the object is placed between F and $2F$.

diagram. A ray starting from the point A of the object and passing parallel to the principal axis passes through the locus F' of the lens, after refraction. A ray starting from the point A and passing through the optical centre O emerges undeviated after passing through the lens. They meet in the point A′ which is the image of A. Similarly we can find the images of the other points. $A'B'$ is seen to be inverted and smaller in size than AB.

Let us put the candle at a point between f and $2f$ and let us put the screen at a point beyond $2f$ to obtain an image of the candle (Fig. 2.38). The image is now bigger in size than the candle though it is inverted as before. The ray diagram for the formation of this image is also shown in Fig. 2.38.

Finally let us bring the candle close to the convex lens. Now look at the candle through the lens. You see an erect and magnified image of the candle (Fig. 2.39). This image cannot be obtained on a screen and so it is virtual. The formation of the image by a ray diagram is shown in Fig. 2.39.

A lens used in this way to get a magnified erect image of a small object is called magnifying glass. Here, the lens of short focal length is usually used.

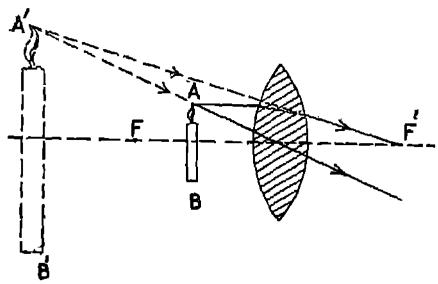


Fig. 2.39. Image formed by a convex lens when the object is placed within the focal length.

Thus the location, dimension and nature (virtual or real) of the image in a convex lens depend on the position of the object with respect to the lens.

§ 27. Laboratory Work No. 3

Aim: To study the image obtained with the help of a convex lens.

Apparatus: A candle mounted on a stand, a convex lens mounted on a stand, a screen mounted on a stand and a graduated wooden plank at least one metre long.

Procedure: 1. As shown in Fig. 2.40 arrange the screen and lens on the wooden plank. Gradually shift the screen away from the lens. Measure the distance between the lens and the screen when you get a sharp image of a distant object (say, a tree) on the screen. This is the focal length of the lens. Mark points F_1, $2F_1$, F_2, $2F_2$ on the graduations of the wooden plank.

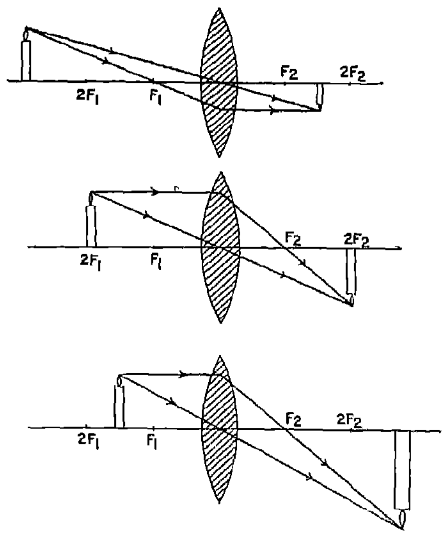


Fig. 2 40. Various positions of the image for different positions of the object.

2. Now place a lighted candle beyond $2F_1$ from the lens and shift the position of the screen placed on the other side of the lens till you obtain a sharp image of the candle. Note the size and nature of the image. Measure the distance between the object and the lens and that between the image and the lens.

3. Now place the candle at $2F_1$, and again obtain the sharp image on the screen. Measure the distance between the lens and the screen and observe the nature and size of the image.

4. Next place the candle between F_1 and $2F_1$, and move the screen to obtain a sharp image of the candle on the screen. Observe the nature, size and distance of the image from the lens,.

5 Finally place the candle between the lens and F_1. Look at the candle through the lens and note the nature of the image that you observe. It is possible to get it on the screen.

6. Draw corresponding ray diagrams and enter these distances there.

7. Based on your observations, complete the following table.

Focal length, F=

Position of the object	*Position of the image*	*Real or virtual*	*Diminished or magnified*	*Erect or inverted*
Beyond $2F_1$				
At $2F_1$				
Between F_1 and 2 F_1				
Between lens and F_1				

QUESTIONS

1. What conclusions do you draw regarding the nature, position, and magnification of the image in different cases ?
2. How does the size of the real image change as we put the candle nearer to the lens ?
3. When is the image of the same size as the object ?

§ 28. The Photographic Camera

A photographic camera (Fig. 2.41) has a light-tight chamber and

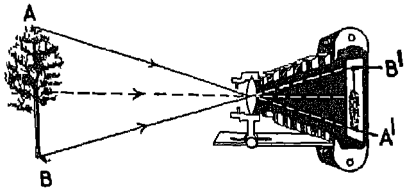


Fig. 2.41. A photographic camera.

an objective mounted into the front wall of the chamber. The objective consists of several lenses. Its purpose is to produce a real image of an object, the picture of which is taken on a light-sensitive film situated at the back wall of the camera.

Before the picture is taken, the object to be photographed is focussed by shifting the objective back and forth until the image of the object in a view-finder or on a ground glass plate becomes sharp.

Rays of light reflected from the object pass through the lens and act on the light-sensitive layer of the film for drawing on it an image of the object. But the image obtained on the film after the picture is taken, is "hidden"—invisible.

Photography is used extensively in modern science and engineering.

§ 29. Projection Lantern

A projection lantern is another optical instrument which is used to obtain a real, enlarged image of an object on a screen so that a large audience can see the picture. As shown in Fig. 2.42, it consists of a

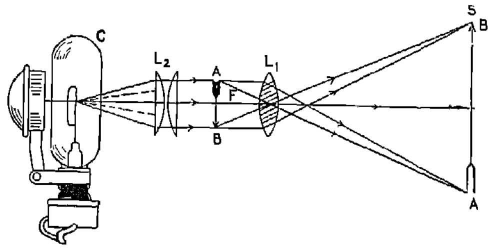


Fig 2.42 A projection lantern.

strong source of light, a system of lenses called the condensing lens and an objective lens. The transparent slide or a film having the picture of the object is put a little beyond the focus of the objective lens so that a real and enlarged image of the object is obtained on the screen. The position of the slide is indicated by an inverted arrow in Fig. 2.42. The object is kept inverted to make the real image on the screen to be erect. The source of light, which may be a carbon arc or a high-powered incandescent lamp, *C*, is placed at the focus of the condensing lens, consisting of two plane convex lenses, so that the light is concentrated on the slide which is uniformly illuminated. Behind the source of light is a reflector which reflects the light emitted by the lamp in the backward direction to be used for illumi-

nating the slide. The image is focussed on the screen by moving the objective lens.

The projector used in the cinema houses is similar in principle to the projector described above though it has additional mechanism so that the film can be moved sideways. About twentyfour distinct separate pictures are thrown on the screen per second, thus giving the impression of continuous motion.

EXERCISE

1. "Double convex lens is called converging lens". Explain, why ?
2. Is it possible to receive high temperature by using double convex lens ? How ?

CHAPTER III

Electrical Phenomena

§ 30. Electricity in Everyday Life

Electricity plays an important role in the life today.

Electric energy transmitted over the wires from thermal and hydro-power stations, operates machines at plants, factories, and farms, and sets in motion trams, trolley-buses, ships and electric locomotives.

Millions of electric lamps illuminate the homes and streets in our towns and villages. We often use electric fans during the summer time, electric heater in winter and other electrical appliances otherwise

Telephone, telegraph, radio communications and television would be impossible without electricity. Most scientific discoveries were made using various electrical apparatus. For instance, they were installed in the earth's artificial satellites used in space probings and the research data were transmitted back to earth by radio.

Various electrical instruments are used extensively in medicine for curing a number of diseases and for x-raying the human body.

Compared with other kinds of energy, electric energy is very convenient because it can be transmitted over great distances by wires and used successfully to operate both, a huge excavator and a tiny electric bulb.

It is impossible to imagine life today without electricity. One must be familiar with the basic laws of electricity in order to understand the principles of operation of the various electrical machines and devices. For this purpose we shall discuss certain simple electrical phenomena.

§ 31. Electrification of Bodies by Friction

In ancient times it was noticed that amber rubbed with flannel is capable of attracting light objects such as paper, pith ball etc.

Later it was established that sealing-wax and ebonite also possessed this ability when rubbed with a piece of flannel or fur, and a glass rod rubbed with silk or paper (Fig, 3.1).

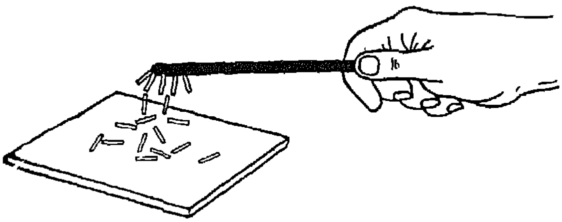


Fig 3 1. An ebonite rod rubbed with a piece of fur attracts small pieces of paper.

(This experiment should be performed by using rubber gloves).

§ 32. Interaction of Charged Bodies—Two Kinds of Electric Charges

These phenomena were named at the beginning of the 17th century as electricity, from the Greek word electron, which means amber. The body which after rubbing attracts other bodies was said to be charged with electricity or that it possessed electric charge.

If an ebonite rod is rubbed with dry flannel both the rod and the flannel will attract small pieces of paper. The experiment proves that both bodies become charged after rubbing. (Fig. 3.2).

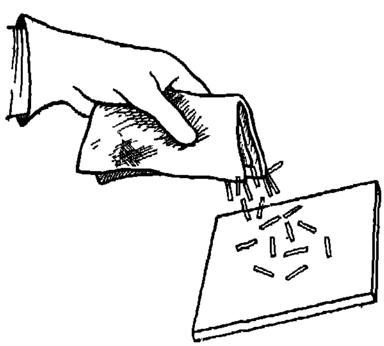


Fig. 3.2. Fur rubbed with ebonite rod also attracts small pieces of paper.

After charging two ebonite rods by rubbing them with a piece of flannel, suspend one as shown in Fig. 3.3 and bring the other

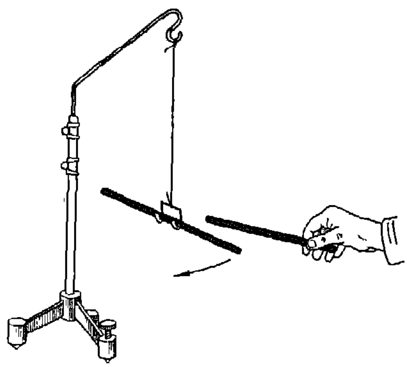


Fig. 3.3. Electrified ebonite rods are mutually repelled.

one near it. You will notice that the charged ebonite rods repel each other.

The result is the same if we take two glass rods rubbed with a piece of silk.

Now bring the charged glass rod near the charged ebonite rod and you will notice that the ebonite rod is attracted to the glass rod. (Fig. 3.4).

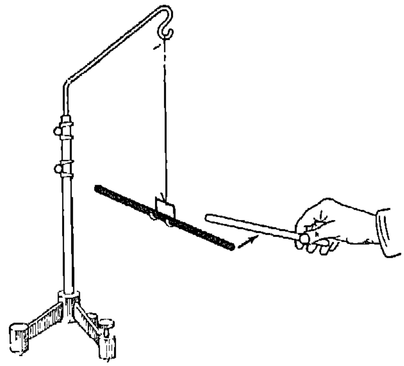


Fig. 3.4. Electrified ebonite and glass rods are mutually attracted.

Thus the charged bodies are either attracted to each other or repelled by each other.

What causes the difference in the interaction of the charged bodies? Evidently the electric charge of the ebonite rod is of a different kind than that of the glass rod.

It was decided conventionally to call the electric charge of the glass rod, rubbed with silk as positive and that of the ebonite rod rubbed with flannel or fur, as negative. Some bodies are charged in the same way as the glass rod, in other words positively while others, as the ebonite rod, i.e., negatively.

Therefore, there are two kinds of electric charges in nature: positive and negative. Positive charges are denoted with the sign + (plus), negative with the sign — (minus). From the above experiments, we can conclude that similar charges repel each other but unsimilar charges attract each other

§ 33. Transfer of Charge due to Contact

A body need not necessarily be rubbed with another body to be charged. It is quite sufficient, for instance, to touch it with some other body which has been electrically charged.

When a charged ebonite rod is brought near a cylinder made of paper suspended by a silk thread, the cylinder will at first be attracted to the rod and then, having touched it, be repelled by it. (Fig. 3.5). Evidently, after touching the rod,

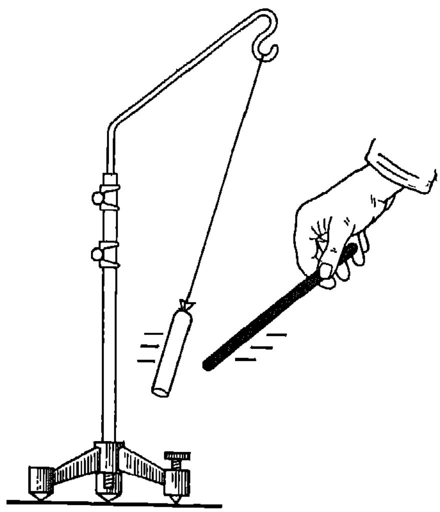


Fig 3.5. A paper cylinder after being touched with an electrified rod is repelled by it.

the cylinder has acquired from it a negative charge. This supposition can be proved by bringing the glass plate with small pieces of paper near this cylinder. So, from the experiment we can draw the conclusion that the body can be charged due to the contact with another charged body. Now we can determine that the charge which this cylinder received is similar to the charge of the body with which it was in contact. To prove this we can bring near to this charged cylinder, a positively charged glass rod to show that it is attracted.

§ 34. Electroscope

When two paper cylinders suspended by silk threads are touched with the charged ebonite rod, they repel each other (Fig. 3.6). By repeating the experiment with glass rods, the same result can be observed.

Consequently, by touching the cylinders with the ebonite rod, we can find out whether the rod was charged or not. If it was charged, the cylinders will repel each other.

Perform the same experiment with two narrow folded strips of paper. Hang the strip on a wire fixed to a glass stand. If the wire is touched with a charged rod, part of the charge will pass through the wire to the strips and the angle between the paper strips will increase (Fig. 3.7).

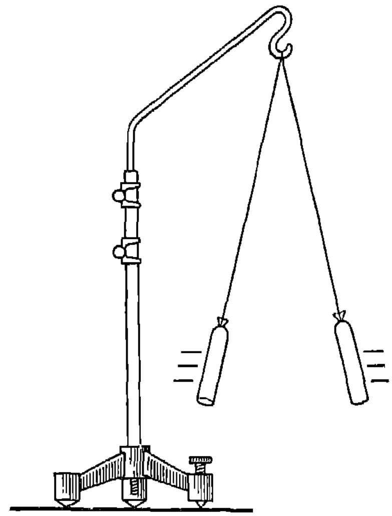


Fig. 3.6. Paper cylinders with like charges repel each other.

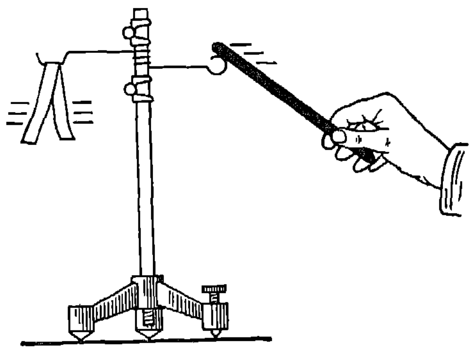


Fig. 3 7 Principle of construction of electroscope.

The electrification of bodies can be detected with the help of any of these experiments. The operation of the electroscope (a device for detec-

ting electrical charge of bodies) is based on the above mentioned physical phenomenon.

A simple electroscope is shown in Fig. 3.8. It consists of two thin

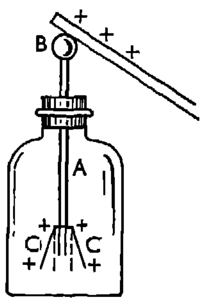


Fig 3.8 Detection of charged bodies by using electroscope

metallic leaves C attached to a metal rod A at the other end of which is a metal sphere B. The end of the rod with the leaves is lowered into a glass jar, which protects them from being damaged and makes it possible to observe them. When the metal sphere is charged, the metallic leaves are charged too. The charged leaves diverge from rod. The greater the charge on the leaves, the greater is the divergence, and vice versa. Fig. 3.9 shows a different design of the electroscope, in which there is a metal sphere or a knob with leaves passing through an insulated cork fitted into metal glassed in frame.

Electroscopes are used for determining the presence of charge in a body. For this purpose we must attach this body to the ball of the electroscope If after contact of these two bodies, the leaves of the electroscope diverge, we know that the body is charged and vice versa. We also use electroscope for comparing the amount of charge on two different bodies.

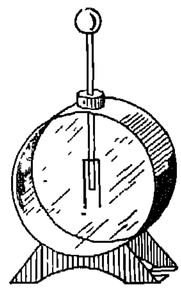


Fig. 3.9. A different type of an electroscope.

§ 35. An Electric Field

The experiments which reveal the attraction and repulsion of charged bodies serve as proof that electrical charges interact at a distance. The nearer the charged bodies are to each other, the stronger is the interaction; the further apart they are, the weaker it becomes.

When studying mechanics, we observed that one body acts upon the other either directly when it comes into contact with the other or through other bodies or media, for

instance, water, air etc. How can we explain the interaction of two charged bodies when they are at a certain distance apart ? It may be that the air between the charged bodies plays an important role. But, experience shows that charged bodies interact even in vacuum. (Fig. 3.10).

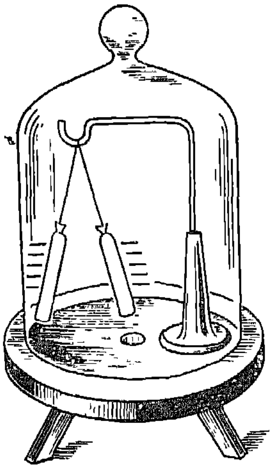


Fig. 3.10 Electrified bodies interact in vacuum

Let us consider again the same demonstration, showing the interaction between two charged bodies (Fig. 3.5). In this demonstration the charged cylinders change their initial state of rest. From the first law of Newton, it can be understood only by the action of forces upon a charged cylinder. Naturally, the space in which there exist forces acting upon an electric charge must have some difference from the space where there is no such force on an electric charge. Therefore, in physics we say that in the space, where such forces are acting on an electrically charged body there exists an electric field.

Every charged body has an electric field surrounding it. We do not feel the presence of an electric field. It can be detected only by the action of the field upon a charged body brought into this field. That explains the interaction of the charged bodies. The electric field surrounding one of the charged bodies, acts upon other charged bodies and vice versa.

Therefore, for recognizing the existence of an electric field at any point of the space, it is necessary to bring a light charged body. If some force acts upon this charged body, it means that an electric field exists at this point. At the same time the action of this force can be recognized by the displacement of this light charged body (charged cylinder suspended by a thread from a stand). The direction in which the charged body moves, depends on the nature of the charge and also on the nature of the charge which produces the electric field. For instance, a light negatively charged body will move towards the positively charged body which produces the field and will

move away from the field produced by a negatively charged body.

This expeiiment also shows that electric field exists at all points in the space surrounding the charged body. (Fig. 3.11). From the

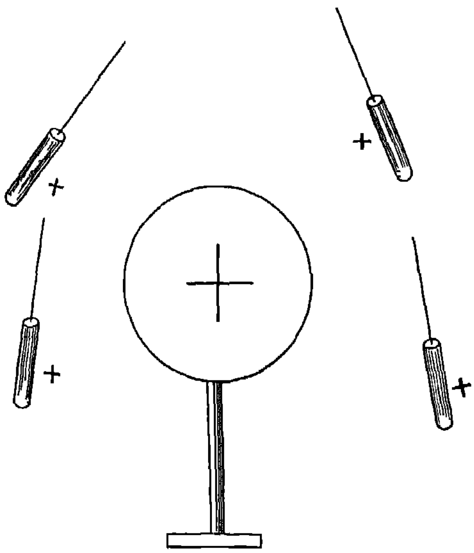


Fig. 3.11. Electric field exists at all points of space around the charged body.

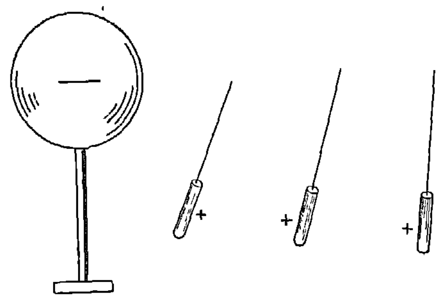


Fig. 3.12 (*a*).

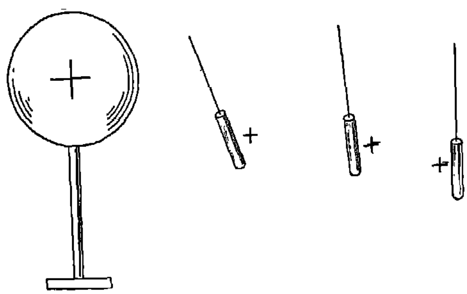


Fig. 3.12 (*b*).
The force of electric field at a point decreases by increasing its distance from the charged body which produces electric field.

same figure, it is easy to understand that the action of electric field is stronger near the charged body which produces the electric field and decreases with the increase in distance. (Figs. 3.12 *a*, *b*).

§ 36. Structure of Matter

To understand the phenomenon of electrification of bodies we must know the structure of matter. You have learned that all bodies consist of molecules. Experiments and physical theories show that the molecule is not the simplest particle of matter. Molecule consists of atoms. It was established experimentally that the structure of atom is also complex. They consist of still smaller charged particles of two kinds—protons and electrons. Protons are positively charged and electrons are negatively charged. The charge of an electron is equal to that of proton. These charged

particles are the smallest charges in nature. Science knows of no smaller charge than that of an electron or proton. These charged particles (electrons and protons) together with neutrons (neutral particles) make up the atom.

The structure of atoms of a certain substance is shown schematically in Fig. 3.13. In the centre is a

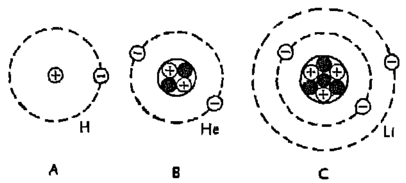


Fig 3.13. Schematic diagrams of atoms of hydrogen, helium and lithium. (+ are protons, — are electrons and plain circles are neutrons).

positively charged nucleus. The nucleus consists of protons and neutrons. The neutron is a neutral particle (having no charge) which has approximately the same mass as proton. The electron is a very light particle, the mass of which is approximately 1/2000th of the mass of a proton. Therefore, the heaviest part of the atom is the nucleus because it consists of heavy particles. Electrons revolved around the nucleus in orbits. Their number of electrons is equal to that of the protons in the nucleus of the atom.

In Fig. 3.13, A shows schematically the atom of the lightest substance, hydrogen. It has only one proton in the nucleus and only one electron revolving around the nucleus. Its orbit is nearly 0.000,000,04 cm in diameter and the nucleus is half a million times smaller.

B shows schematically the atom of helium. Its nucleus consists of two protons and two neutrons. Consequently two electrons revolve around it.

C schematically shows the atom of the metal lithium. Its nucleus has three protons, and four neutrons. Consequently, three electrons revolve around it.

The most complex of all the atoms found in natural conditions is that of uranium. Its nucleus has 92 protons and 146 neutrons with 92 electrons revolving around it.

Although atoms consist of positively and negatively charged particles, the equality of the positive and negative charges makes them electrically neutral.

§ 37. The Role of Electrons in the Electrification of Bodies

Now you know that all bodies are made up of atoms. Atom consists of some particles which possess electric charges. Bodies are neutral because each atom is a neutral particle and so the total body must be neutral.

In some phenomena atoms of a body can lose one or several of its electrons. The positive charge of nucleus is then no longer balanced by the total charge of the remaining electrons. So the atom will be positively charged, and the body will also be positively charged.

In a positively charged body there are less electrons than protons. When there is an excess of electrons, the body is charged negatively. To charge a body means to disturb the equilibrium between the number of protons and electrons in it. Now let us consider again the experiment of electrification of a body by friction. For this, take two plates, one of a metal covered with leather and the other of glass. Each of them should be of equal area and fitted with an insulating handle. Rub these two plates against each other and separate them by taking them in each hand. Bring these two separated plates near small pieces of paper. Some of the paper pieces are attracted to each of the plates. (Fig. 3.14).

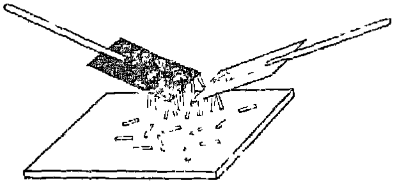


Fig. 3.14. By rubbing, two bodies are electrified.

This establishes the fact that both are electrified. Now put them together so that the rubbed surface of one is completely covered with the rubbed surface of the other and bring them again near the pieces of paper. In this case none of the paper pieces is attracted to the combination showing thereby that they are no longer electrified (Fig. 3.15). This can only happen when the charges developed on each plate are of opposite nature and at the same time equal in quantity.

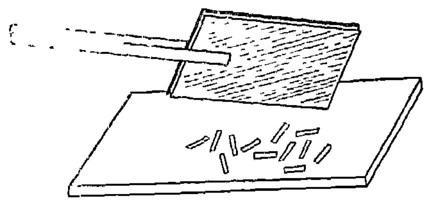


Fig 3 15. By rubbing two bodies, they are electrified and the two charges are different in nature but equal in quantity.

So the above experiment shows that the charges developed on the two bodies are of opposite nature and of equal quantity.

In other words, due to friction positive charge is developed on one body and negative charge of equal quantity on the other body.

You know that in mathematics, the sum of (+5) and (—5) is equal to zero. So here equal quantity of positive and negative charges put together are completely neutralised.

On the basis of the structure of matter we can easily explain the process of electrification of bodies. When we rub a glass plate with a leather plate, some electrons pass from the glass plate to the leather plate due to the good contact between these two bodies. Therefore, the glass plate possesses less electrons than protons and the glass plate becomes positively charged. At the same time the leather plate, which receives some electrons, has more electrons than protons and becomes negatively charged. Thus, due to the rubbing of these two bodies, the bodies are electrified differently (nature of charge may be positive or negative) but in equal quantity.

In order to separate the charges, the force of attraction of the unlike charges has to be overcome. Electrification of bodies entails a certain expenditure of energy. For instance, mechanical energy is used during electrification by rubbing. In other cases, electrification entails the expenditure of other types of energy.

In the atoms of metals, the bond between some of the electrons and the nucleus is weak. They are easily separated from the atoms and haphazardly move inside the metal. Such electrons are called *free electrons.* Electrons (negatively charged) which are not connected with atoms can move in the metal under the action of an electrical field.

Some substances such as ebonite, glass, ceramic, pure water, air etc., do not possess free electrons.

§ 38. Conductors and Insulators

When studying thermal phenomenon you learnt that substances are divided into good and poor thermal conductors according to their ability to transfer heat. They are also divided into conductors and non-conductors or insulators according to their ability to conduct electric charges.

Let us make the following experiment. Charge an electroscope (Fig. 3.16), and then connect it

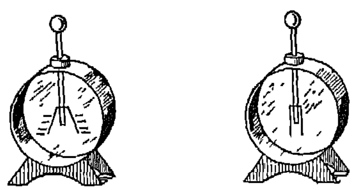


Fig. 3.16. Two electroscopes. One is charged and the other is uncharged.

with an uncharged electroscope by means of a wire with ebonite handle. As soon as the wire touches the spheres of both the electroscopes, the leaves of the first electroscope will draw together a bit while

those of the second electroscope will diverge; this means that part of the charge from the first electroscope was transmitted through the wire to the second (Fig. 3.17).

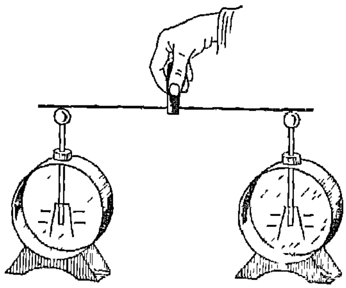


Fig. 3·17. By connecting the two electroscopes mentioned in Fig. 3.16, part of the charge passes from one electroscope to the other.

By charging the first electroscope and connecting it with the second by means of a wire or strips of various materials, we can establish that some of there wires conduct electric charges and others do not.

Substances which conduct electric charges are called electric conductors. Substances which do not conduct electric charges are called non-conductors or insulators.

Metals, wet soil, acqueous solutions of salts, acids and alkalis, graphite (for instance, pencil graphite) are good conductors of electricity. The human body is a conductor, too. This can be proved by a simple experiment: touch the charged electroscope with your hand and you will notice that the leaves converge. The charge passes from the electroscope into the earth through your body and the floor.

Silver, copper and aluminium are the best metal conductors. Electric wires are made usually from copper or aluminium.

Ebonite, porcelain, rubber, various plastics, silk, carbon, oils, rank high among insulators. Indoor electric wires have a rubber insulating coating and a cotton sheathing or a plastic tubing. Outdoor wires are fixed to poles by means of porcelain insulators (Fig. 3.18).

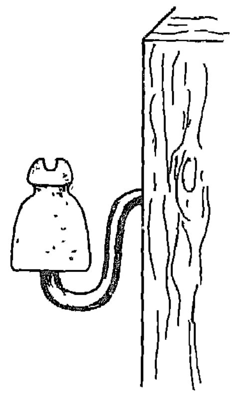


Fig 3.18. Porcelain insulator for fixing wires.

§ 39. Earthing

When a charged body is connected to the earth, the charge passes

into the earth and the body is no longer charged. How can this phenomenon be explained ?

When we connected a charged electroscope with an uncharged one (Fig. 3.17), the charge was divided between the two. It can be said that the charge was equally divided, and approximately half of the initial charge remained in the first electroscope. If we connect two similar uncharged electroscopes to the charged electroscope, one-third of the charge would remain in the first electroscope. With three electroscopes, one fourth of the charge would be left, with nine electroscopes, one-tenth and so on and so forth. The larger the number of the uncharged bodies connected to the charged electroscope, the greater part of the charge passes over to these bodies and the less remains in the electroscope.

The earth is very much larger than any of the bodies we have to deal with in practice. Therefore, no matter what the charge of the body is when the latter is earthed, practically the whole charge passes into the earth, and only a very small fraction of it remains.

EXERCISE

1. Why can an ebonite rod be charged by rubbing while holding it in the hand and a metal rod cannot ?
2. Examine the insulation of an electric wire.

§ 40. Electrification of Bodies by Induction

If an electrically charged rod is brought near a discharged electroscope, the electrical field of the charges induces some charge on the electroscope and its leaves diverge. It means that the electroscope is charged. Remove the rod, the leaves will collapse and the electroscope will be discharged. (Figs. 3.19 *a*, *b*, *c*). From where do the charges appear in the electroscope, when a charged body is brought near it ?

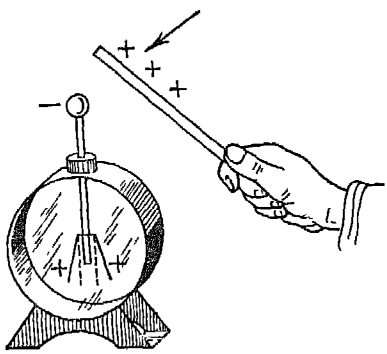


Fig. 3.19 (*a*). Divergence of the leaves when a charged body is brought near the electroscope.

Free electrons are distributed

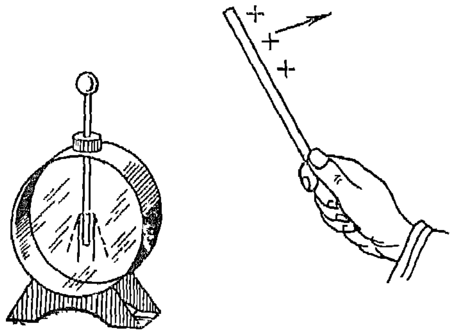


Fig. 3.19 (*b*) If the charged body is taken away, the electroscope is discharged.

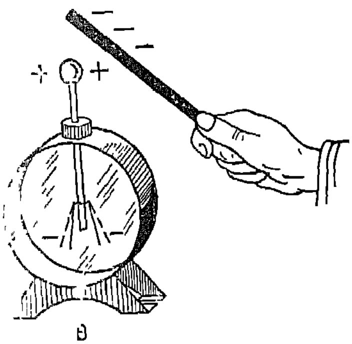


Fig. 3.19 (*c*). Electrification of electroscope by induction.

uniformly along the metal rod of a discharged electroscope, balancing the positive charges of the nuclei of atoms. This is shown schematically in Fig. 3.20 in which electrons are depicated as dots inside the outline of an electroscope rod.

When a charged body is brought near the electroscope, the rod will be in the electrical field. Under its effect, free electrons rearrange themselves in the metal. They will

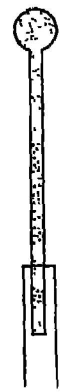


Fig. 3.20. In uncharged conductor, electrons are distributed uniformly.

be crowded in the upper part of the electroscope rod if the body is charged positively and move to the lower part of the rod if the body is charged negatively, because the electrons will be repelled by the electrical field (Fig. 3.21). In both

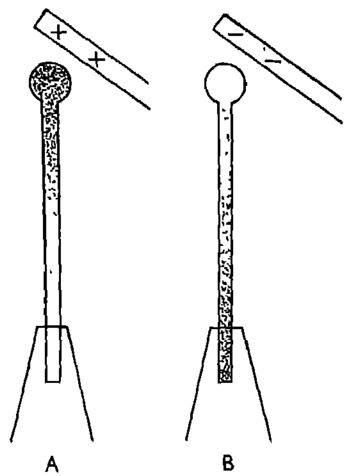


Fig. 3.21. The uniform distribution of electrons is disturbed, when the conductor is in electric field.

cases the tips of the electroscope rod will be charged. On the tip closest to the body there will always be a charge of the opposite sign to that of the body and on the far end, the charge of the same sign as that of the body.

Electrification of the conductor in the field of a charged body is called *electrification by induction*. When the inducing charge is taken away electrons once again rearrange themselves uniformly in the conductor, which becomes discharged once again.

With the help of electrification by induction not only the charges in the conductor can be temporarily separated but the conductor can also be charged permanently.

When an uncharged conductor B mounted on an insulating stand is brought near the negatively charged body A, the conductor will be charged by induction in the field of the charged body A (Fig. 3.22). Under its action, free electrons will

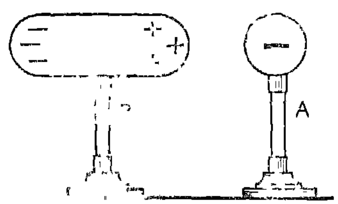


Fig. 3.22. Separation of charges in a conductor placed near the charged body.

move to those parts of the conductor which are farthest from the charge. If you earth the conductor by touching it with your finger, for instance as shown in Fig. 3.23, the electrons will immediately flow to

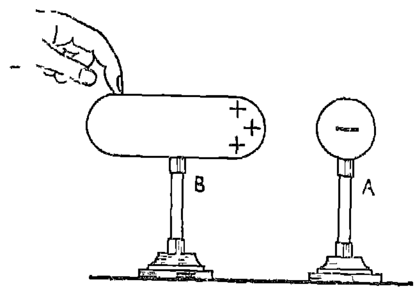


Fig. 3.23. When the conductor is earthed, electrons in the conductor B escape to the ground.

the earth. After the hand is removed there will be a lack of electrons in the conductor B and its charge will be positive (Fig. 3.24).

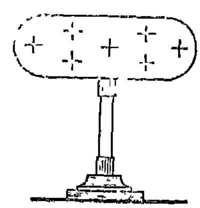


Fig. 3.24. The conductor becomes charged after the inducing charge is removed.

The conductor can be charged negatively by the same method. For this purpose it should be placed in the positively charged field. The conductor will be negatively charged after being earthed.

Charging by induction explains, in particular, the attraction of various objects to the charged bodies. An uncharged object, for instance a paper cylinder, is charged by induction near the charged body. Charges in the cylinder interact with those of the induction field, although the interaction of the negative and positive charges is different. The unlike charge is attracted by the charged body more strongly than the like charge is being repelled by it, since the like charge is always removed further from the inducing charge. As a result the cylinder will be attracted to the charged body.

EXERCISE

1. When bodies are electrified by rubbing, a certain amount of electricity passes from one body to another. Describe in what direction will the electrons move when an ebonite rod is rubbed with felt.
2. Small pieces of paper are attracted to a charged rod far more strongly when they are placed on a conducting earthed plate than on an insulator. How do you explain this ?
3. When a conductor charged by the induction is earthed, charges flow to the earth regardless of the spot where we touch the conductor. Explain this.

41. Electrical Phenomena in the Atmosphere

From days immemorial people observed lightning and heard thunder during thunderstorms. However, the nature of these phenomena was learnt only after extensive research conducted in the 18th century by the Russian scientists M. Lomonosov and G. Richter and by the American scientist B Franklin (Fig. 3.25). They discovered that lightning is nothing but a huge electric spark or an atmospheric discharge.

Before a thunderstorm, considerable electrical charges accumulate in thunderheads. This process is facilitated by the fact that charges cannot escape into the ground from the clouds that are high up in the sky.

When two thunderheads with unlike charges approach each other, a powerful electric field is set up between them. Under its effect the electrons can start moving from the negatively charged thunderhead across the air, which becomes heated by the electric current and becomes a rather good conductor. As a result a lightning flash occurs between the two charged clouds (Fig. 3.25). The charges stored up in the clouds pass via the channel that was

Fig. 3.25. Lightning between two charged clouds.

formed by the heated air. The discharge lasts for only a small fraction of a second.

Rapid and energetic expansion of the heated layers of air produces sound waves which we hear as thunderclaps. Lightning flashes and thunderclaps occur simultaneously but we usually hear the clap of thunder after we have seen the flash of a lightning. This is due to the fact that sound in the air propagates with the velocity of 340 m/sec and light propagates with a million times greater (300,000 km/sec) velocity.

Characteristic rolls of thunder can be explained by the fact that sound waves from various parts of a lightning do not arrive to the earth simultaneously. Besides, sound is reflected from the clouds and various objects on the ground, which also prolongs the sound.

An electric discharge, lightning, can occur not only between two clouds but also between a charged cloud and the earth (Figs. 3.26).

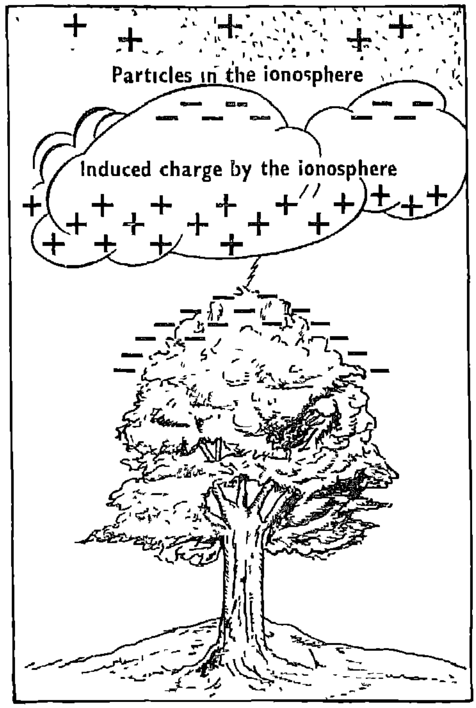


Fig. 3.26 The nature of lightning between the charged cloud and the earth.

When, for instance, a negatively charged cloud comes sufficiently close to the earth, it induces, particularly on high ground, a powerful positive charge, followed more often by a stroke of lightning between the cloud and the earth.

Lightning lining can be many miles long.

Lightning can split a tree and very often it is the cause of fires if it strikes a building. If a person happens to be near the spot struck by lightning, he can be severely burnt or even killed. Artificial respiration should be immediately administered to the victim.

Lightning rods are installed on the roofs and on other installations to protect them from lightning. The lightning rod is a metal rod with a sharp tip (Fig. 3.27), better still, a bundle of sharp tips. The rod is connected by means of a thick metal conductor with a large metal plate buried deep in the ground. When lightning strikes the rod, all the charges pass into the earth through the conductor without doing any harm to the building. Thus the metal rod provides an easy path for the lightning to follow. Besides it also provides an opportunity for the induced charge on the building to leak off. Good earthing is the most important thing in lightning protection. If the earthing is poor, lightning is liable to damage the rod and the building itself.

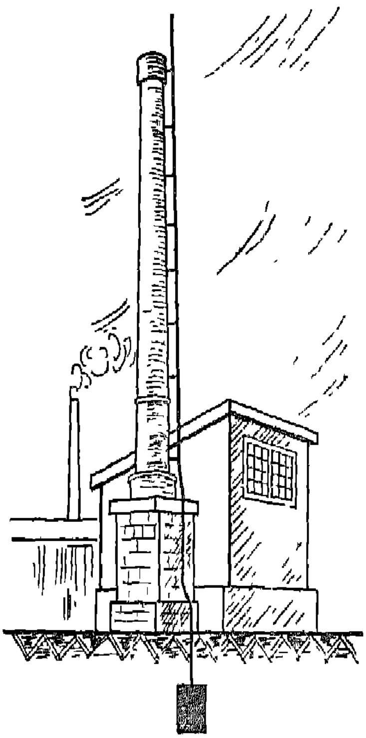


Fig. 3.27. Lightning rod installed on a plant's chimney

CHAPTER IV

Electric Current

§ 42. What is Electric Current?

We have already learnt about the transfer of charges, for instance, when a charged electroscope is connected with a non-charged one. Free electrons flow in the connecting conductor under the effect of the electric field of the charged body.

Electric current in metals is directed flow of electrons.

To find out the conditions necessary to produce electric current in a metal, we shall repeat the demonstration given earlier.

For this purpose, we take two electroscopes, one charged negatively and the other charged positively. The value of charge on each electroscope is equal because the divergence of the leaves of the electroscopes is same. Now, if we connect them by a metal rod with an insulating handle, it is easy to find out that these two electroscopes are discharged quickly.

This result can be explained only by the direct motion of negative charges (electrons) from the electroscope which is charged negatively to the electroscope charged positively. So, in this experiment we produce electric current during a very short period of time. The electrons in the metal rod move in a definite direction by the action of the electric field produced by charged electroscopes.

Therefore, the reason of existence of this current for only a short period of time is due to the disappearance of electric field.

If we want to keep the electric current flowing in a conductor for a prolonged time, the electric field must be maintained. Hence, the charge of the body should be continuously supplied.

§ 43. Electric Cells

Towards the end of the 18th century, the Italian physicist Volta discovered that when two different metals are in contact with acid, they are charged—one charged positively and the other charged negatively.

On the basis of this phenomenon, Volta constructed the first chemical source of 'electric current' which is known as galvanic cell (after another Italian scientist Galvani, a contemporary of Volta, who discovered the phenomenon of electric current). You are familiar with the dry cells used for torches, radio sets etc.

The Voltaic cell shown in Fig. 4.1, consists of a zinc plate and a copper plate, immersed in a solution of sulphuric acid. Interacting with the acid, the zinc plate becomes more negatively charged than the copper plate. An electric field is set up around the charged plates. If we now connect the two plates by metal wires to a small electric bulb we can observe the bulb glowing due to the current flowing through it.

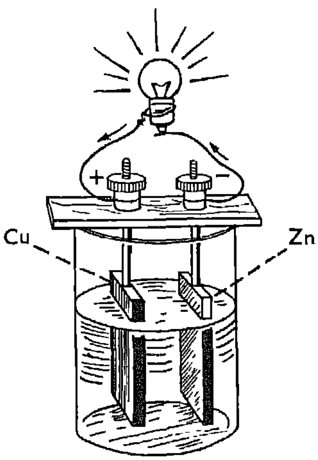


Fig. 4.1 Simple Voltaic cell.

An electron flows from zinc to the copper plate in the outer circuit, i.e., the bulb. Today dry cells are used extensively for supplying electric current. They are called "dry" because instead of the usual solution they are filled with a thick paste.

One such cell is shown in Fig. 4.2 and its construction is illustrated in Fig 4.3. The cell consists of a zinc container and a carbon rod in a bag filled with

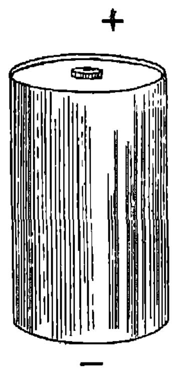


Fig. 4.2. Dry cell

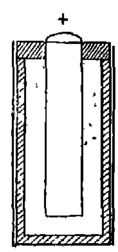


Fig. 4.3. Construction of a dry cell,

manganese dioxide (MnO_2) and graphite. The electrolyte is in the form of a paste of ammonium chloride and saw dust, instead of solution. The zinc container is placed in a cardboard box and the top is sealed with tar.

The carbon rod serves as the cell's positive and its negative terminal is soldered to the zinc container.

Several small dry cells connected together make up a battery for a pocket torch (Fig. 4.4). One cell

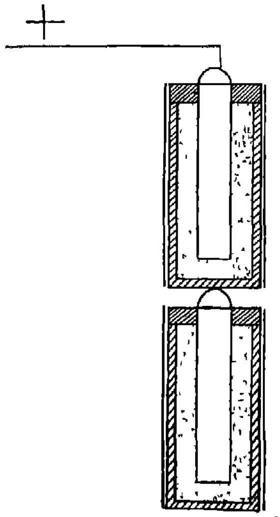


Fig. 4.4. Battery of two dry cells.

is insufficient for supplying the lamp with enough power. For the torch to shine brightly, two cells are interconnected to form a battery. The carbon rod of the first cell is connected with the zinc container of the second.

§ 43. The Storage Batteries

When a dry cell operates, zinc and the solution are used up. After some time the cells have to be replaced. Storage batteries provide a far more convenient source of electric current.

The simple storage battery or accumulator consists of two lead plates immersed in a sulphuric acid solution If you make such a storage battery and test it with the help of an electric bell or a small electric bulb, you will find that it does not operate.

For the storage battery to become a source of current, it has to be charged. For this purpose, an electric current from another source is passed through the storage battery.

After some time the battery will be charged and can be used as an independent source of current.

Today lead or acid storage batteries as well as ferro-nickel or alkaline batteries are used widely.

Fig. 4.5 shows the general view of a motor-car storage battery.

The use of storage batteries is wide and varied. They are used for illuminating railway carriages, for supplying power to head lights of motor-car and to start its engine (starter). Powerful storage batteries

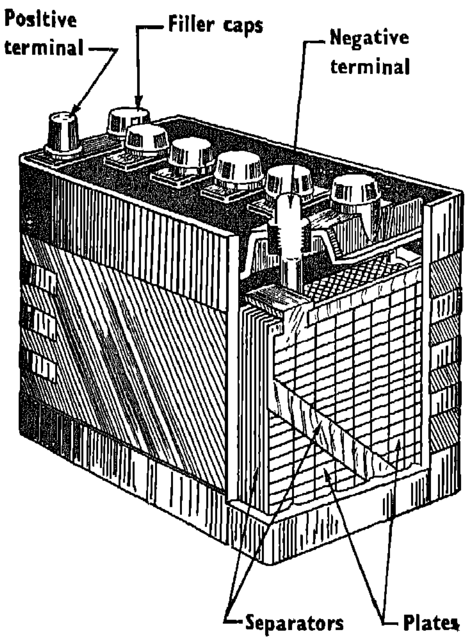


Fig. 4 5. Storage battery (acid type).

are used to propel submarines under water. Radio transmitters and scientific apparatus of the earth's artificial satellites are powered with the help of storage batteries of another type.

§ 44. Effects of Electric Current

The current flowing in a conductor can produce some effects. Let us examine them experimentally.

1. If a current flows through a wire suspended between the two stands (Fig. 4.6), the wire will gradually become heated. It will expand and sag,

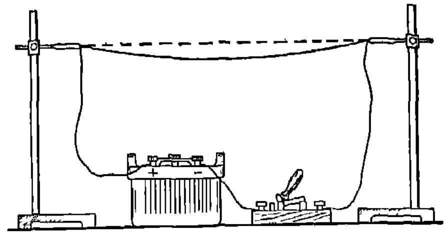


Fig. 4.6. Heating effect of electric current.

The electric current always heats the conductor in which it flows, thus displaying its *thermal effect.*

This effect is utilized in incandescent lamps, in electric stoves, irons, and in hundreds of other ways.

2. If an insulated copper wire is wound round a steel nail and a current flows through the wire (Fig. 4.7), the nail acquires magnetic properties. It will attract small nails and other steel objects. Switch off the current, and they will fall. The nail has lost its magnetic properties.

An experiment shown in Fig. 4.8 serves as another proof that an electric current possesses *magnetic properties.* A steel rod suspended from a spring is drawn into the coil of a solenoid when the current starts to flow in the coil. When the current is switched off, the spring again pulls the rod up because the magnetic properties of the coil have disappeared.

The magnetic property of a

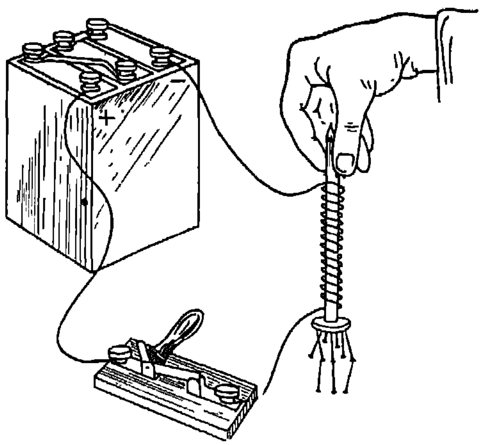


Fig. 4.7. Magnetic effect of electric current.

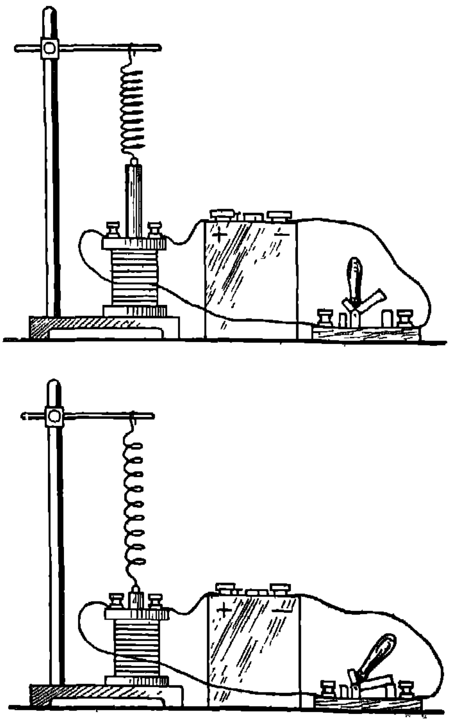


Fig 4.8. Magnetic effect of a solenoid with current.

current is of great practical importance. It is made use of in the design of electrical motors, in telephones, telegraphs, testing and measuring instruments and so on.

3. Immerse two carbon electrodes—in a diluted solution of copper sulphate and connect them to the terminals of a storage battery (Fig. 4.9). After several minutes

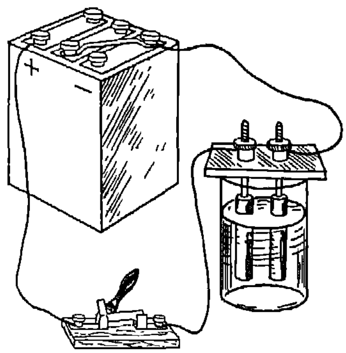


Fig. 4.9. Chemical effect of an electric current.

remove the electrodes from the solution. We will observe that a reddish coating of copper has appeared on the electrode which was connected with the negative terminal of the storage battery. Copper has been deposited on the electrodes from the copper sulphate solution. The longer the current flows through the solution, the more copper is deposited on the electrode. The deposit of a metal from its salt solution when the current flows through it, displays the *chemical effect* of the current,

This phenomenon is made use of in the production of aluminium, copper, magnesium and a number of other metals, as well as in nickel— and chromium-plating of metal objects in order to protect them against corrosion (rusting).

Electric current is of great practical importance because of the many ways in which we can use the three principal effects it produces: heating, chemical and magnetic. Each effect can be used to detect an electric current flowing in a conductor.

§ 45. The Unit of Charge

Charge an electroscope so that its leaves diverge. Then add more charge to it so that the divergence of the leaves increases.

Evidently, the charge in the second case is greater than in the first. If the electroscope was charged negatively, it can be said that in the second case, there were more free electrons in the electroscope than in the first. The experiment demonstrates that an electric charge can be smaller or larger. The charge value is called the amount of electricity.

To measure the quantity of electricity, it is necessary to determine its unit. On the example of charging the electroscope, it is seen that the quantity of electricity can be measured by the excess or shortage of electrons in a body. However, this method is rather inconvenient because it is impossible to count small charge formed in the comb while combing our hair.

In order to establish a practical unit for measuring an electric charge it is convenient to make use of its chemical effect. We know that the longer the current flows in the salt solution, the greater is the quantity of metal deposited on the electrode connected to the negative terminal of the storage battery.

It was agreed that the unit of electricity should be the quantity of charge which should be passed through a solution of the silver nitrate ($AgNO_3$) for 1.118 mg of silver to be deposited on the electrode. The unit was named after the French physicist *Coulomb* (1736—1806) who discovered the law of force of interaction of electrical charges. It is abbreviated as C.

One Coulomb of electricity is equal to the charge of 6,250,000, 000,000,000,000 (6.25×10^{18}) electrons or protons.

EXERCISE 18

1. Which of the three effects of an electric current is used in charging] a storage battery ?
2. Give examples of the use of the thermal effect of an electric current.
3. Carefully take apart an old dry cell, examine its construction and compare with figure in the text.
4. Find the quantity of electricity that has passed through a solution of copper sulphate if the amount of copper deposited on the electrode is 0.4 g.
5. How many Coulombs of electricity have to be passed through a solution of silver nitrate to deposit 0 559 g of silver ?
6. During the experiment of detecting the chemical effect of a current in Fig. 4.10 180, coulombs of electricity is passed through a solution of copper sulphate. Find out the mass of copper deposited on the electrode.
7. To charge a storage battery, it is essential to know which one of the terminals is negative and which one is positive. How can you tell this by using the chemical effect of a current ?
8. Pour some water into a glass and dissolve a few crystals of copper sulphate in it. Immerse two strips of tin in the solution and connect it to the terminal of a torch battery. Observe copper being deposited on one of the strips.

§ 46. Electric Circuits and Its Component

We have said earlier that cells and the storage battery serve as sources of electric current. You may have noticed that in order to light an electric bulb in a room it is necessary to put on the switch. For drawing current from a battery, connecting wires are used and the current flows only when the external path between the terminals of the battery is closed. Such an arrangement where the current flows from the source through conducting wires and a switch is called a *circuit*. The electric wire is used for distribution of current from the mains to different parts. The wires are connected in wooden cases inside the walls and you do not see them outside. If the wire in any part of the circuit breaks then the current does not flow. Different types of switches are used in an electric circuit. Some types of switches, and their conventional symbols are shown in Fig. 4.10. Drawings, which illustrate various methods of connecting the appliances to the circuit are called diagrams of a circuit. Various appliances and

instruments in the circuit are represented by some symbols given in Fig. 4.11.

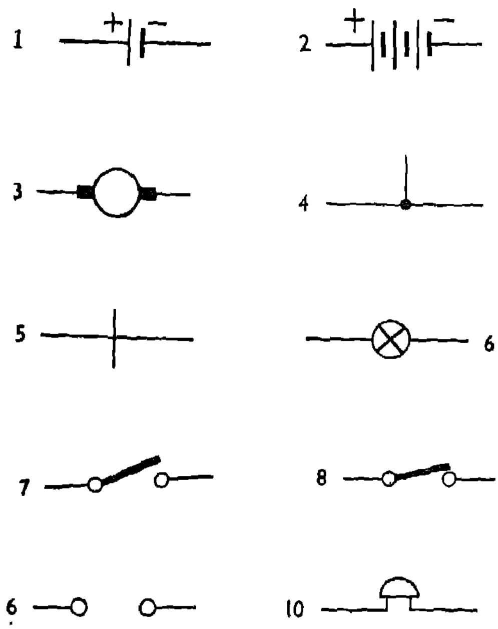


Fig. 4.11. Conventional symbols used in diagrams
(1) Cell;
(2) Battery of cells (storage battery);
(3) Generator or motor;
(4) Wire joint;
(5) Wire cross (without joining);
(6) Electric bulb;
(7) Switch (without connection);
(8) Switch (connected);
(9) Terminals;
(10) Door bell.

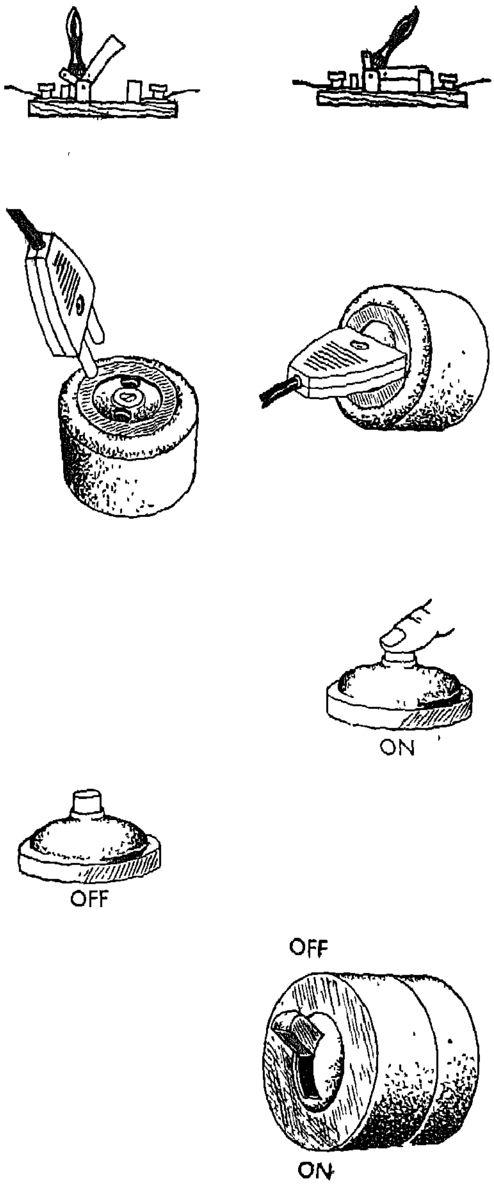


Fig. 4.10. Switches from top to bottom: one pole switch off—on; Plug and socket off—on; Push button off—on; Switch used in lighting circuits.

The direction of current

You already know that negatively charged particles called "electrons" flowing in a metallic conductor such

as electric wire are responsible for the flow of electrical current. According to convention, the direction of flow of current in a circuit is considered to be the direction from the positive pole to the negative pole, though the electrons actually move in an opposite direction.

§ 47. The Value of Current

Like all other physical quantities current can also be measured. In order to understand the strength of a current let us perform some simple experiments. Make an electric circuit by using a storage battery, a small torch bulb, a vessel containing a solution of copper sulphate and two carbon electrodes, and a switch. When the circuit is closed, we will find the bulb glowing and the copper deposited on one of these electrodes.

If you connect two batteries in the circuit instead of one, you will find that the glow of the bulb becomes brighter and more copper is deposited on the electrodes during the same interval of time than in the first experiment with one battery only. The glow of the bulb as well as the amount of the copper deposited on the electrodes will indicate that there is a difference in the two experiments.

The strength of the current in the circuit in the second experiment is greater than in the first. In other words the strength of current in a circuit is determined by the effect it produces.

The value of current is determined by the quantity of electricity flowing in a circuit in a unit interval of time. The strength of a current can be defined as the quantity of charge flowing in a conductor in unit time, i.e., one second. The current can be expressed by giving the following relation

$$i = \frac{Q}{t}$$

where Q is the total quantity of charge flowing during the time t and i the current flowing in the circuit. The practical unit of measuring current is called ampere. According to the previous definition, the quantity of charge is expressed in practical units, i.e., coulomb. The *ampere* can be defined as the current flowing in a conductor when one coulomb of charge flows in one second. For measuring current, sometimes, a smaller unit is used which is 1/1000th of an ampere and is called a milliampere "$1\,mA = 0.001\,A$". The unit of current was expressed in this way in Physics for a long time. Now, according to the international system of units one ampere is not expressed by using the chemical action

of current. In the new system one ampere is expressed in terms of the magnetic property of electric current.

§ 48. The Ammeter

You have learnt that current is a measurable quantity and it is expressed in ampere for practical measurements. The measuring instrument used for measuring current is called ammeter. Fig. 4.12 shows an

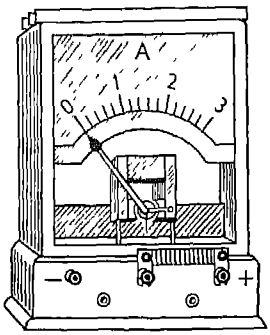


Fig. 4.12. Ammeter (demonstration type).

ammeter. In circuit diagram it is represented by a circle with a letter *A*. The amount of deflection indicates the strength of the current. In an ammeter the needle moves over a graduated scale. As a precautionary measure, the needle should not go beyond the scale. When you learn in detail about the construction of an ammeter you will know that an ammeter should always be connected in series in an electric circuit. While using an ammeter you will find that the terminals are marked by + and —signs Sign + should be connected to the positive terminal of a battery. An ammeter used for measuring current can be placed in any part of the simple circuit, because current flowing in a circuit is the same everywhere.

This can be shown by an experiment, the arrangement of which is shown in the Fig. 4.13. The current

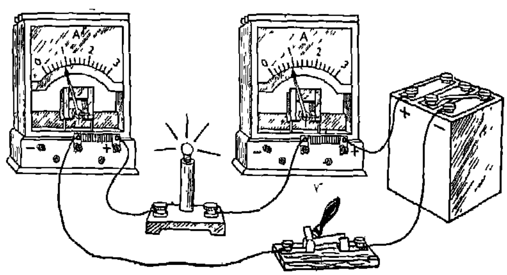


Fig. 4 13. Current is same in all parts of the circuit.

indicated by the ammeter will be same if it is placed anywhere in the circuit.

§ 49. Laboratory Work

Aim: To set up an electrical circuit and to measure the current in its various parts.

Apparatus: Storage battery, two small electrical lamps mounted on a stand, a switch, an ammeter and connecting wires,

Procedure: Draw the circuit diagram first, get it checked by the teacher, and set up the circuit accordingly. Take care that the ammeter is connected properly, and then,

(1) write down the ammeter readings; then change the position of the ammeter and connect it in the position *A* and *B*. Compare the value of the current in each case.

(2) perform the same experiment by taking two lamps. Use another bulb in the circuit and note down the intensity of light. Compare the readings with the results of the first experiment without the bulb.

CHAPTER V

Resistance and Potential

§ 51. The Resistance of Conductors

Let us consider a simple electric circuit which consists of a storage battery, an ammeter, a small electric bulb and a switch (Fig. 5.1).

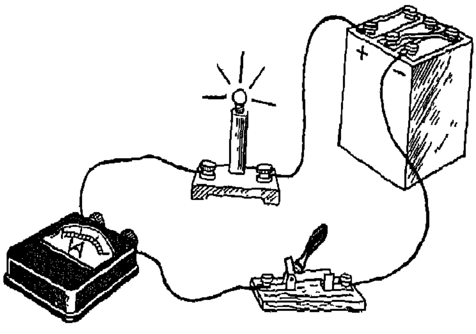


Fig. 5.1. Simple electric circuit consisting of a storage battery, a small electric lamp, and a switch.

Switch on and read the electric current. Now, include one more electric bulb with it and find out the reading of the ammeter. This experiment shows that the current in the second case is less than that in the first one. From this experiment we can draw the conclusion that the current depends on the specific feature of the circuit. The ability of a conductor to influence the flow of current in a circuit is called its *resistance*. The smaller the current flowing in a wire, the greater is the resistance and vice versa. So we can determine the value of the resistance of a conductor by measuring the amount of electric current which flows in the circuit.

Now we want to find out what actually influences the resistance of a conductor. For this purpose, we set up an experiment as mentioned below. Use a storage battery, an ammeter, a thin steel wire which is attached to a board and a switch as shown in Fig. 5.2. Close the switch and note down the readings of the ammeter. Connect another wire of the same diameter and length but of a different material. You will find that the current noted by the ammeter will change. This experiment shows that the amount of resistance depends on the property of the material of the wire. Perform the same experiment by using another wire three times longer than the first one. You will find that the current indicated by the ammeter

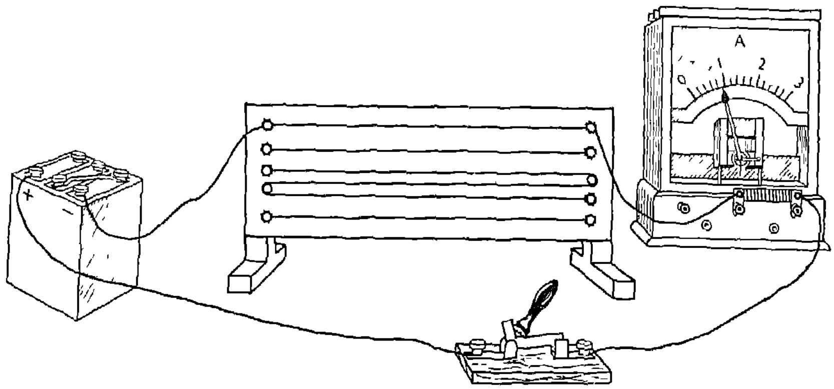


Fig. 5.2. Arrangement for studying specific properties of a metal conductor.

will be one-third of its value in the previous case. The resistance of the wire used in the second experiment was greater than that of the steel wire having the same length and area of cross-section. The resistance of the longer wire is greater than that of the shorter one. This shows that the resistance of the wire is directly proportional to the length of the wire. Now take two wires of the same material and same length but of different cross-section. First, connect one wire and take the reading of the ammeter. Then replace this wire by another with bigger cross-section and find out the current. The result of the experiment shows that the current in the second experiment is greater than that in the first one. In other words, we can say that the resistance of the wire in the second experiment is less than that in the first one.

We can conclude from these experiments that the resistance of a conductor is inversely proportional to the area of its cross-section. On the basis of these conclusions we can write that the resistance of a particular conductor is directly proportional to the length of the wire and inversely proportional to the area of its cross-section. The resistance of the wire also depends on the property of the material.

§ 52. Units of Resistance and Specific Resistance

Like all other physical quantities resistance also has a unit. The resistance of a mercury column of length 106.3 cm and of cross-section 1 sq. mm of 0 degree centigrade is called *ohm*. Ohm was determined in this way for a long time. Like unit of electric current, the unit of

resistance in international system is now expressed in a different way. The resistance of a conductor is generally denoted by 'R' and the symbol used for ohm is Ω. For practical measurements, resistance is expressed in kilo ohm, ($1k\ \Omega = 1000\ \Omega$ and $1M\ \Omega = 1{,}000{,}000\ \Omega$). To calculate the resistance of a conductor, we must know the resistance of the wire which has a length of one meter and cross-section of 1 sq. mm. This value which characterises the resistance of such a wire is called *specific resistance* of the material. It is denoted by the Greek letter ρ. To calculate the value of resistance R of a wire, we use the formula, $R = \rho\ l/s$ where R is the resistance, l the length of the wire and s the area of cross-section.

If we measure R in ohm, l in metre and s in mm^2, the unit for $l\rho$ results as *ohm* mm^2/m.

The values of specific resistances of some common materials are given in the table below:

Substance	*Specific resistance* $\left(ohm \frac{mm^2}{m}\right)$
Silver	.016
Copper	.017
Aluminium	.028
Tungsten	.055
Iron	.10
Lead	.22
Nichrome	1.1
Carbon	40-50

§ 53. Rheostats

In practical work it is sometimes necessary to regulate current in a circuit. May be you have observed how the light fades out in a cinema or in a theatre. This is achieved by reducing the current in the circuit. These devices used for decreasing or increasing the current in a circuit when the source of current remains the same are called *rheostats*.

A wire made from a material with large specific resistance (Figs. 5.3 *a*, *b*) can be used as a simple

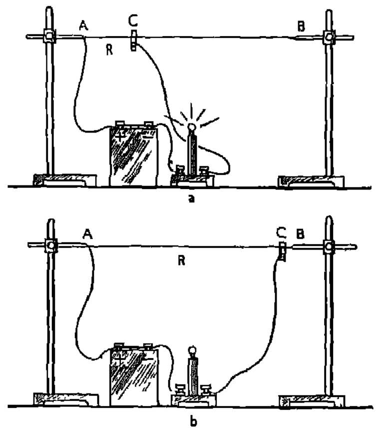


Fig. 5.3. A simple rheostat:
(*a*) resistance is small and the lamp is glowing;
(*b*) resistance is large and the lamp does not glow.

rheostat. The wire is connected to the circuit with the help of terminal A and sliding contact C. By shifting the slider, the length of the section AC connected to the circuit

can be either increased or decreased. By changing the length of the wire its resistance is changed, and consequently the current in the circuit.

In rheostats the wire is wound on a ceramic cylinder (Fig. 5.4),

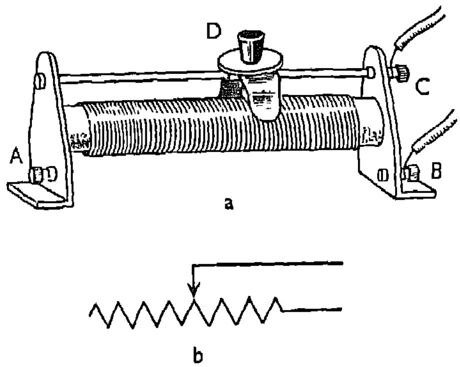


Fig. 5.4. Rheostat with a slider.

the ends of wire being connected to the terminals *B* and *C*. The wire is covered with a coating of enamel insulation so that the current should flow along the wires and not between the turns. A slider *D* moves along a metal rod fixed over the winding. Its contact slides along the turns. The enamelled coating wears off under the contacts due to the friction and the current passes from the turns to the slider and then to the rod and to its terminal *C*. The device is called a rheostat with a sliding contact or a slider.

The rheostat is connected to the circuit by means of the terminal *A* or *B* and the terminal *C*. Its resistance can either be increased or decreased by shifting the slider along the rod. Each rheostat has a plate indicating the resistance of the winding and the maximum permissible current. It cannot be exceeded, otherwise the winding heats up and gets burnt.

In schematic diagrams rheostats are indicated as shown in Fig. 5.4, *b*.

Another type of a rheostat is shown in Fig. 5.5.

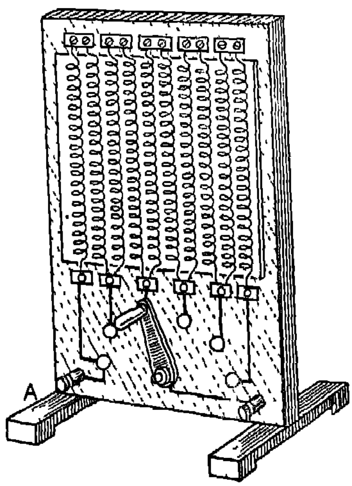


Fig 5.5. Step rheostat

EXERCISE 19

1. The resistance of each spiral of the rheostat shown in Fig. 5 5, is 2 ohms. What is the resistance introduced into the circuit when the lever is positioned as shown in the figure ? You want to introduce 16 ohms into the circuit. What should be the position of the lever ?
2. A sliding rheostat is connected to a circuit (Fig. 5 3). Draw a diagram of the circuit in your notebook. Show the paths of a current by arrows In what direction should the slider be shifted for the lamp to glow brighter ?
3. What should be the length of a nickel wire 3 sq. mm in cross-section used for making a rheostat of 750 ohms ?
4. Calculate the value of the resistance of a copper wire having the length of 5 meters and cross-section 10 sq. mm.

§ 54. Potential

From the concept of electric current and specific feature of electric circuit it follows that certain conditions are necessary for producing electric current.

Electric current is the directed motion of electric charges, so, naturally the first condition is the existence of free charges.

From the structure of the conductors you know that in all metal conductors, there are a lot of free electrons. Under an electric field these free electrons in the metal conductors produce electric current But in the absence of electric field in the metal conductor, these free electrons are in random thermal motion.

To produce an electric current, an electric field is necessary. Electric field in any circuit is formed by electric cells, storage batteries or other sources.

Let us consider a simple electric circuit consisting of a storage battery, a bulb, an ammeter and a switch Switch on the circuit and note down the reading of the ammeter. Then, in the same circuit, change the source of the current by using two storage batteries and later on three batteries. In each case, take the readings of the ammeter. This experiment shows that the value of the current is greater when the number of storage batteries are more, other conditions being same.

In other words, we can conclude that the value of electric current is greater when a greater electric field is produced by the batteries.

Therefore, each source of electric current (storage batteries) differs in

potential. Potential of an electric source is a physical quantity which characterises the electric field producing it. Thus, potential of a source is greater when greater current is produced in the circuit, the other conditions remaining same.

If we consider the flow of water in the water pipes by using a pump it is easy to understand that this flow of water is due to the difference in pressure. So the pressure in the pump is necessary for the flow of water.

Therefore, potential in electric circuit is analogous to the pressure in the pump. Potential exists not only at the terminals of the battery but also between any two different points of electric circuit.

§ 55. Unit of Potential

Potential of an electric source is measured by the work done by the force of electric field in moving one unit of positive charge from one terminal of the source to another through the complete circuit.

The unit of the potential is *volt*. When the work done is equal to one Joule due to the displacement of one coulomb of electricity through the entire circuit, the source of current is said to possess potential of one volt.

The same units we can express in another way. The potential across two points of the circuit is one volt if the work done is equal to one joule when one coulomb of charge is displaced from one point to the other. The potential is denoted by the letter V and the unit by small v.

To get an idea of potential of different sources, some typical values are given below:

Potential across voltaic cell terminals—1.1 volts.

Potential across dry cell terminals —1.5 volts.

Potential across storage battery— 2.2 volts.

Potential of the electric mains— 220 volts.

Potential between charged cloud during lightning— 1000,000,000 volts.

§ 56. Voltmeter

An instrument called a voltmeter is used for measuring the potential (potential difference) across the terminals of a source of current or potential between any two points of a circuit. It is connected across two points of a circuit where the voltage is to be measured. The school type voltmeter is shown in Fig. 5.6. The letter V is printed on the graduated scale of the voltmeter. In diagram, it is denoted by a small circle with

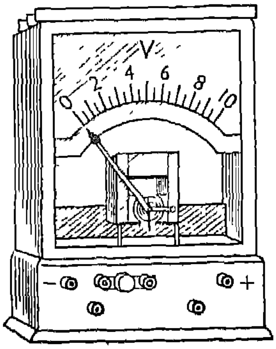


Fig. 5 6. School voltmeter.

a letter V inside it. The design of a voltmeter is based on the magnetic effect of electric current. One of the terminals is marked + and another —. Its positive terminal should be connected to the positive pole and the negative to the negative pole of a battery. If the connection is not correct the voltmeter will be damaged. The voltmeter in a circuit is connected differently from an ammeter. The ammeter is connected in series with devices in which the current is to be measured. Its resistance should be small, compared to the other parts of the circuit. The resistance of an ammeter is usually of the order of 1/100 and 1/1000 of an ohm—or less. To measure the voltage across any part of the circuit, for instance across the terminals of a *rheostat* in the circuit, the voltmeter is connected in parallel, i.e., across the ends of this part of the circuit as shown in Fig. 5.7. In

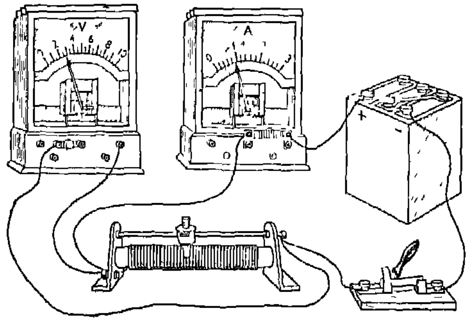


Fig. 5.7. Electric circuit for measuring the current in the circuit and voltage on the rheostat.

the same figure you can see that the ammeter is connected in series. The resistance of the voltmeter is sufficiently great so that the current in the circuit remains same when the voltmeter is connected to it. The resistance of the coil in a voltmeter is made of the order of 100 and 1000 ohms. To measure the potential across the terminals of an electric source i. e., a battery, a voltmeter is connected directly to the battery as shown in Fig. 5.8.

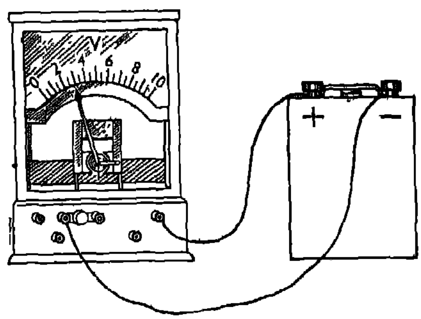


Fig. 5.8. Connection of a voltmeter across the terminals of the storage battery.

EXERCISE 20

1. Indicate the points of similarity and difference between an ammeter and a voltmeter.
2. Draw a schematic diagram of a circuit consisting of a battery, a lamp, a rheostat and a switch. Where would you insert an ammeter in the circuit to measure the current ? How should a voltmeter be connected to measure the voltage in the lamp, across the rheostat terminals ?
3. How will you check the correctness of the reading of a voltmeter if you have another one known to be correct ?

§ 57. Laboratory Work No. 5

Aim: *Measuring voltage across various parts of the circuit.*

Apparatus:

Storage battery or dry cells, a low-voltage lamp mounted on a stand, a voltmeter, a sliding rheostat, a switch and connecting wires.

Procedure:

1. Find the voltage across each of the cells or the battery terminals. Compare the results and draw the conclusion.

2. Connect the lamp, rheostat and the switch in series: close the circuit and adjust the intensity of the lamp with the help of the rheostat.

3. Measure the voltage across the terminals of the rheostat and across the lamp several times changing the resistance. Compare the results with the overall voltage of the rheostat and the lamp.

4. Draw the circuit diagram of the devices in your notebook for measuring voltage across the terminals of the storage battery, those of the rheostat, across the lamp respectively and of the overall voltage in the circuit. Write down the results.

§ 58. The Relations between Current, Voltage and Resistance—Ohm's Law

Let us make a circuit consisting of a storage battery, a rheostat, a switch and an ammeter and study experimentally how the current in a conductor depends on the voltage. To measure the voltage across the terminals of the rhoestat, insert a voltmeter into the circuit as shown in Fig. 5.9. Close the circuit and take the readings of both the volt-meter and the ammeter.

Connect a similar storage battery to the first one and close the circuit once more. The voltmeter will show a voltage, double of the previous value and the ammeter will also show

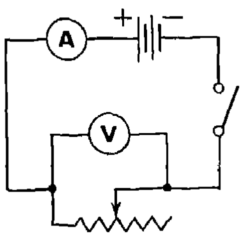


Fig. 5.9. Circuit diagram for illustrating Ohm's law.

a current, double of the previous value. After connecting a third battery we shall notice that both the voltage and the current have increased three times.

Hence, the conclusion can be drawn from the experiment that *the resistance being constant, the current in a conductor is directly proportional to the potential difference across its ends.*

Now we shall change the resistance, keeping the same number of storage batteries. By increasing the resistance two times we notice that the current drops half of its previous value. When we decrease the resistance by half, the current becomes double.

Therefore, potential being the same, the current is greater in a wire, the resistance of which is smaller.

In other words, *the current in a wire is inversely proportional to the resistance.*

Studying the relation between the current, the potential and resistance, the German Scientist Ohm established in 1827 the following law :

The current in a wire is directly proportional to the potential difference between its two ends and inversely proportional to its resistance.

Ohm's law can be written in the following way,

$$I=\frac{V}{R},$$

where I is the current flowing in a circuit, V is potential difference and R the resistance of a circuit. The formula can also be written in the form,

$$V=\frac{I}{R}$$

for calculating the potential difference when the value of the current and resistance in a circuit is known.

Ohm's law is one of the basic law of electricity. It is used for calculating the current, potential difference and resistance in a circuit.

If the potential difference and current in a circuit are known, the following relation can be used to calculate the resistance,

$$R=\frac{V}{I}$$

Let us consider some problems, where the formula given above is used,

1. Calculate the current in an electric range if the voltage of the mains is 220V and the resistance of the range's spiral is 22 ohms.

V=220 *Volts* According to
R=22 ohms Ohm's law,
I—?

$$I=\frac{V}{R};$$

$$\therefore I=\frac{220\ Volts}{22\ \text{ohms}}$$
$$=10A.$$

2. An ammeter indicates a current of 0.2 A. What is the potential difference across the ends of an 8 ohms resistance inserted into tl circuit ?

I=0.2A According to tl
R=8 ohms Ohm's law, V=I
V—?

$\therefore V=0.2A\times 8$ ohn
$=1.6V$

3. An ammeter showing curre in a lamp reads 0.35A. Find tl resistance of the lamp's filame if the voltage across the lamp 3.5V.

I=0.35A According to t
Ohm's law, $R=I/V$
V=3.5V
R—?

$$R=\frac{3.5V}{0.35A}=10\ \text{ohn}$$

EXERCISE

1. Find the current in a 600 ohms rheostat inserted into a 220 V circuit
2. Find the current through a voltmeter if the resistance of the voltmeter is 200 ohms and the voltmeter reads 10 V.
3. What potential difference should be applied across the ends of a wire with a resistance of 1,000 ohms to obtain a current of 1mA in it.
4. The calculated value of an ammeter resistance for measuring currents up to 10A is 0 02 ohms Why can the ammeter be not connected to the terminals of a 220 V mains ?
5. Three conductors of resistances, 6 ohms, 12 ohms and 24 ohms respectively, are connected in series to the circuit An ammeter reads 150mA. Find the overall voltage in all the conductors and in each one separately.
6. A 0.015 ohm ammeter is connected to measure current in a 12 ohms rheostat. The ammeter reads 6A Find the potential difference across the rheostat and the ammeter
7. Find the resistance of a lamp filament if a 0.12 A current is flowing through the lamp and the potential difference across it is 220 V.
8. A voltmeter reads 220 V and 15 mA current is passing through it. Find its resistance.

§ 59. Laboratory Work No. 6

Aim: *To find the resistance of a wire with the help of an ammeter and voltmeter.*

Apparatus:

A storage battery or a cell battery, two conductors (coils), a laboratory ammeter and voltmeter, a rheostat, a switch and wires.

Procedure:

1. Make a circuit as shown in Fig. 5.10. Write down the reading of the ammeter in a table.

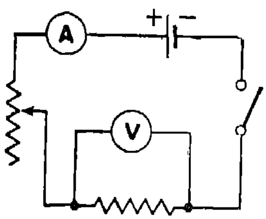


Fig. 5.10. Circuit diagram for laboratory work No. 6.

2. Connect the voltmeter to the ends of the conductor under study. Measure the potential difference across it and write down the results in the table.

3. Shift the rheostat slider to new position and measure the current and voltage once more and note down the readings in the second column of the table. Repeat for the third time with still other position of the slider,

4. Using the experimental data, calculate the resistance of the first conductor and find the mean value from the three observations.

5. Repeat the experiment with the second conductor.

		Current	Voltage	Resistance	Mean
First conductor	1				
	2				
	3				
Second conductor	1				
	2				
	3				

§ 60. Laboratory Work No. 7

Aim: *To study the connection of conductors in series.*

Apparatus:

Storage battery, or a torch battery, 5 to 100 ohms rheostat, two coils of wire, laboratory ammeter and voltmeter, a switch and connecting wires.

Procedure:

1. Assemble a circuit consisting of storage battery, a rheostat, two coils and an ammeter connected in series.

2. Calculate the resistance of the circuit and its individual elements by measuring current and the

potential difference across the circuit and across its individual elements. Take measurements with three various values of current.

3. Find the mean values of the resistances and write them in the table.

Voltage	*Current*	*Potential diff across the 1st resistance, r_1*	*Potential diff across the 2nd resistance, r_2*	*Total resistance*	*Resistance of r_1*	*Resistance of r_1*
1						
2						
3			*Mean*	.	..	

§ 61. Conductors in Series

The components of an electric circuit such as electric apparatus, switches and connecting wires possess certain resistance and are called *resistors.*

The total resistance of the circuit depends on the resistance of all its resistors and the way they are connected.

The resistors are said to be connected in series when the same current passes through all of them. The circuit diagram of resistors connected in series are shown in Fig. 5.11. In the earlier section we have already described circuit in which a battery, a lamp and switch were connected in series.

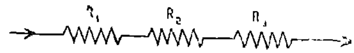


Fig. 5.11. Series connection of resistors.

The resistance of the circuit increases when new resistors are connected to it in series. We either increase or decrease the total resistance of the circuit by connecting or disconnecting resistors in series. As the resistance increases, the current in the circuit decreases and as the resistance diminishes, the current becomes greater.

Fig. 5.12 shows the circuit diagram of series connections of some

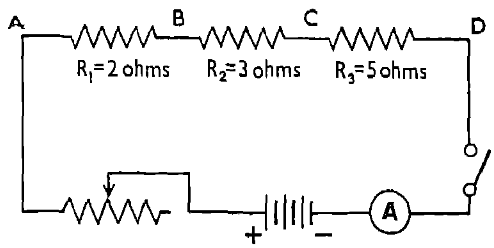


Fig. 5.12. Circuit diagram of series connections.

resistors. Let us try to find out the values of current, and resistance of the conductors connected in series. The value of resistances shown in the circuit are as,

$$R_1=2 \text{ ohms}$$
$$R_2=3 \text{ ohms}$$
$$R_3=5 \text{ ohms}$$

The total resistance of the combi-

nation of resistors in series is equal to sum of the individual resistances.

Therefore,

$$R_0 = R_1 + R_2 + R_3 = 10\Omega$$

From this we conclude that

The current in all resistors connected to the circuit in series is the same; the resistance of the combination of resistors is equal to the sum of the individual resistances.

§ 62. Parallel Connection of Resistors

When several resistors are connected between two points so that the current divides between them and then rejoins, they are said to be *in parallel*. This type of connection of resistors or electric apparatus is most widely used in practice.

The circuit diagram of three resistors connected in parallel is given in Fig. 5.13. The current

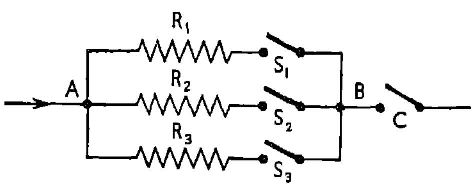


Fig. 5.13. Parallel connection of resistors.

branches off at point A and rejoins at point B.

Experiment shows that if we measure electric current before the circuit is divided, and also in each branch, then for the total current I in the non-branching circuit and the current in the individual branches as I_1, I_2 and I_3, we have a simple relation,

$$I = I_1 + I_2 + I_3.$$

Obviously, the potentials across the individual conductors are the same; it is equal to the potential between A and B.

Thus we conclude that *when the conductors are connected in parallel, the current in the main circuit is equal to the sum of the currents in the branches. The potential difference across all branches is the same.*

The advantage of the parallel connection lies in the fact that each electric apparatus can be switched on or off independently from the rest of the circuit with the help of switches S_1, S_2 and S_3.

The switch C of the mains closes or opens the entire circuit.

Parallel connection of electric apparatus is widely used in industry and household purposes.

For example, electric lamps in lighting circuits, electric motors in plants and factories and many other electric apparatus are connected in parallel. This type of connection is used in each case when it is necessary to control the current, in each individual electric apparatus.

Work and Power

§ 63. Work Done by Electric Current

You have already studied that mechanical work is done by human beings and animals by using their muscular force. Still there are some harder mechanical works which are most difficult to be done by muscular energy. The. energy of electric current helps people to do harder mechanical works and produce heat for their needs.

You might have seen the use of electrical energy in everyday life. Electric fans in houses, electric trains as a means of transport, different types of machines in mills and factories of some industries, electric cranes in construction works, and water pumps for irrigation, all these use electrical energy.

So, in all these above examples, mechanical work is done by using electrical energy of the electric current. Now let us calculate the work done by an electric current and heat produced by it. For this consider a simple electric circuit as shown in Fig. 6.1.

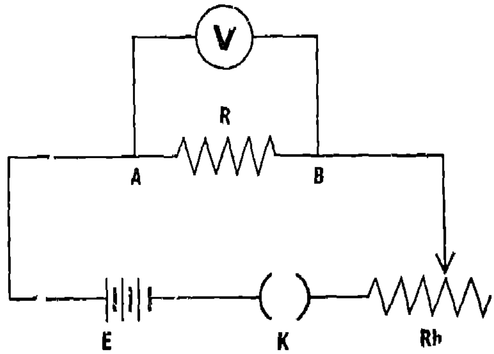


Fig. 6.1. Voltmeter reading the potential difference between the two ends of a current carrying conductor.

Here the voltmeter is reading the potential difference between two points of a current carrying conductor. You have already understood the significance of the potential difference between two points in an electric circuit. It has been defined as the amount of work done by electric field of the source of current in moving unit charge from one point to the other. If 1 volt is the potential difference between two points A and B of this circuit, it means that 1 joule of work will be done if 1 coulomb of charge flows in this section of the circuit.

If the voltmeter reads 2 volts, the work done in moving 1 coulomb of electric charge will be 2 joules. So, if the potential difference between two points as shown by the voltmeter is V volts, the work done by electric current in moving 1 coulomb of charge will be V joules.

So, we see that when the potential difference between two points is V volts, the work done by electric current in moving 1 coulomb of charge when indicated in joules is numerically equal to V.

Since the work done W_1 in case of 1 coulomb of charge flown under the influence of the potential difference V is given as $W_1=V$ (joules), so the work done W_2 in case a charge equal to 2 coulombs flows between the same potential difference V is given as $W_2=2\times V$ (joules) and the work done W_3 in case a charge equal to 3 coulombs flows between the same potential as $W_3=3\times V$ (joules).

So when q coulombs of charge flow between the same potential difference, work done W will be given as $W=q\times V$ (joules).

Therefore, to calculate the amount of work done in moving electrical charge, we use the formula:

Work done by the electric current =(*Amount of electric charge moved*) $\times$(*potential difference across the section under consideration*).

If we denote work by W, charge by q and potential difference between two points of the electric circuit by V, we have,

$$W=q\times V. \tag{i}$$

Here, we see that to measure the work the quantity of charge flown, in the section of the circuit under consideration must be known. But practically, it is not so convenient to measure the quantity of charge. Therefore, in practice, we use another formula. To derive this new formula you will have to recollect the relation between the charge and the electric current. The current has been defined as the *quantity of charge flowing through the conductor per unit time.* If we denote current, charge and time by I, q and t respectively, we have,

$$I=\frac{q}{t}.$$

From the above equation we get,

$$q=I\times t.$$

If we substitute q by $(I\times t)$ in equation (i), we get the relation,

$$W=I\times t\times V. \tag{ii}$$

From the formula (ii) it can be understood that the work of 1 joule is done, for example, when 1 ampere of current flows for 1 second through a section of electric circuit with a

potential difference of 1 volt. So we have,

$$1\text{J} = 1A \times 1V \times 1S.$$

Here, if I is expressed in amperes, V in volts and t in seconds, the work W is expressed in joules.

The formula (*ii*) is used in practice to measure the work done by an electric current. Here, all the quantities on the right hand side of the equation (*ii*) are easily measured. Current I is measured with the help of an ammeter, potential difference V with the help of a voltmeter and time t with a watch. Here, it is to be noted that the work done by electric current does not manifest in the form of mechanical work only, but also in the form of heat produced in the conductor through which the current flows. For example, the current flowing through an electric heater, an electric stove etc. produces some quantity of heat in them.

§ 64. Power of Electric Current

You know from mechanics that power is the amount of work done per unit time,

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}}.$$

If P stands for power, W for work and t for time, we have

$$P = \frac{W}{t}. \qquad (i)$$

From this formula, it is easy to understand that if work done W by an electric current is measured in joules and time t in seconds, the power P is measured in $\frac{\text{joule}}{\text{second}}$. This unit, $\frac{\text{joule}}{\text{second}}$ is known as *watt*,

i.e., $1 \text{ Watt} = \frac{1\text{ J}}{1\text{ S}}$.

Now, we know that in the case of electrical current I amperes flowing for t seconds under a potential difference of V volts, the work done is given as,

$$\text{Work} = V \times I \times t. \qquad (ii)$$

Hence the formula for power can be obtained by substituting W by $(V \times I \times t)$ in equation (*i*) as

$$P = \frac{V \times I \times t}{t} = V \times I.$$

or

$$P = I \times V. \qquad (iii)$$

So, from the formula (*iii*) it is obvious that to calculate the power of an electric current the value of current and the potential difference across the section under consideration must be known.

Here, the product of potential difference in volts and the current in amperes results in the power of electric current in *Watt*.

Watt is a very small unit of power. So, in practice we use bigger

units of power such as *hectowatt* and *kilowatt*, where,

1 hW (hectowatt)$=$100W (Watt)

1 kW (kilowatt)$=$1000W (Watt).

Ratings of some of the power sources and consumers are given below:

Pocket torch lamps	1 W
Desk fans	25 W to 50 W
Lighting lamps	15 W to 200 W
Street lamps	300 W to 500 W
Electric iron	300 W
Electric stove	600 W
Electric silocutter	10 kW
Lathe electric motor	5 kW to 15 kW
Trolley bus motor	85 kW
Electric train motor	4000 kW
Turbo-generator	50 kW to 300,00 kW

§ 65. Calculation of Work Done by Current in Terms of Power and Time

You can also calculate the work done by a current if you know the power of the current and the time of flow of the current. It will be understood as follows:

You know that power P is given as

$$P=\frac{W}{t}.$$

So,

$$W=P\times t$$

From this, we can calculate the work done by electric current in terms of power and time. Thus, if power P is expressed in watt and time t in second, the work ($W=P\times t$) will be expressed in joules. This is evident from the relation,

$$1 \text{ watt} = \frac{1 \text{ joule}}{1 \text{ second}}$$

From this relation, we get 1 joule$=$ 1 watt $\times$ 1 second. Since joule is a small unit of work, so in practice, some bigger units are used for convenience. Some of them are as follows:

$$\begin{aligned} 1 \text{ watt-hour} &= 1 \text{ watt} \times 1 \text{ hour} \\ &= 1 \text{ watt} \times 3600 \text{ seconds} \\ &= 3600 \text{ joules} \end{aligned}$$

$$\begin{aligned} 1 \text{ hectowatt-hour} &= 1 \text{ hectowatt} \times 1 \text{ hour} = 100 \text{ watts} \times 3600 \text{ seconds} \\ &= 360000 \text{ joules} \end{aligned}$$

$$\begin{aligned} 1 \text{ kilowatt-hour} &= 1 \text{ kilowatt} \times 1 \text{ hour} \\ &= 1000 \text{ watts} \times 3600 \text{ seconds} \\ &= 3600000 \text{ joules} \end{aligned}$$

Here, 1 watt-hour is the work done by a current of 1 watt power during its flow for 1 hour. So to calculate the work of current, it is necessary to know the power rating and the time during which it has been consumed. The rated power of the consuming appliance is usually given on its body or its certificate.

Example

A 60 W electric bulb is burning 4 hours daily in a room. Find the work done by the current in 30 days.

$$\begin{array}{ll} P = 60\text{ W} & \text{Work} = P \times t \\ t = 30 \text{ days} & = 60\text{ W} \times 4\text{h} \times 30 \\ \hline \text{Work} - ? & = 7200\text{Wh} \\ & = 7200\text{ W} \times 3600\ s \\ & = 25920000\text{ J.} \end{array}$$

You can also express the work done in kWh in the above example as follows:

$$\begin{aligned} \text{Work} &= 60\text{W} \times 4\text{h} \times 30 \\ &= 7200\text{ Wh} \\ &= 7.2\text{ kWh.} \end{aligned}$$

Now, we can show that the above work expressed in kWh and joules are equal to each other. We know that,

$$\begin{aligned} 3600000\text{J} &= 1\text{ kWh} \\ \therefore\ 25920000\text{J} &= \frac{25920000}{3600000}\text{ kWh} \\ &= 7.2\text{ kWh.} \end{aligned}$$

So, from this example, it is easy to understand how to compare two values of the same electrical work in two different units. You have seen that when one of the values is converted into the second unit, both the values become equal to each other.

§ 66. Electric Meter

The total energy given by a current in a consumer is measured by an instrument called *meter*.

One such meter is shown in Fig. 6.2. Here, we see two wires

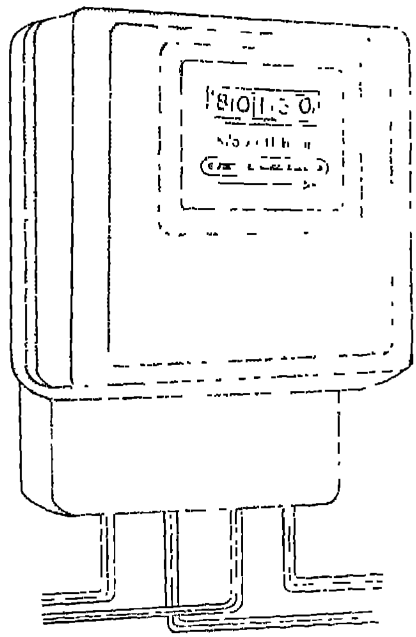


Fig. 6 2. Electric meter

from the source of power and two wires from consumer's circuits connected to the meter. There is a disc inside the meter. It can be seen through the glass on the front of the instrument. When there is a current in the consumer's circuit, the disc of the meter rotates. At constant potential difference between the terminals of the meter, more power is consumed, when there is more current flowing through the consumer's circuit. The speed of the rotation of the disc depends upon the strength of the current. The more is the current in the circuit of the consumer, the faster is the

speed of rotation of the disc. So the speed of rotation of the disc increases with the increase in power consumed in the circuit. Thus, the rate of work done by the current can be measured in terms of the speed of rotation of the disc. The total rotations of the disc are counted by a special counter. Thus, the total rotations of the disc determine the work done by the current. The work done by the current is measured by the meter and is shown in its scale in *kilowatt-hour*.

Thus to know the amount of electric energy spent (work done by the current) during a certain period, the meter's readings in the beginning and at the end of the period are noted. The difference of these two readings gives the amount of energy spent in *kilowatt-hour*. In some meters the last figure on the meter's scale has a different colour or is separated by a point. Such figure indicates the tenths and hundredths of a kilowatt-hour. To determine the cost of the consumed electrical energy, the work expressed in kilowatt-hour is multiplied by the residential cost of 1 kWh.

$$\text{Total cost (in rupee)} = \text{kWh} \times \frac{\text{rupee}}{1\text{kWh}}$$

Example

A meter reads 801.30 kWh at the end of the month, while a month ago it read 792.05 kWh. Calculate the total cost of electric energy consumed if 1 kWh costs Rs. 0.20.

Work done by the electrical current up to the beginning of the period = W_1

Work done by the electric current to the end of the period = W_2

Work done by the electric current during the period

$$\frac{W = W_2 - W_1}{\text{cost} - ?}$$

$$\text{Cost} = \frac{\text{Rupee}}{1\text{ kWh}} \times \text{work done } (W)$$

$$\text{Cost} = \frac{\text{Rs. } 0.20}{1\text{ kWh}} \times (801.30 - 792.05)\text{ kWh}$$

$$= \text{Rs. } 0.20 \times 9.25$$

$$= \text{Rs. } 1.850$$

§ 67. Laboratory Work No. 8

Aim: *To find out the power of the current consumed by an electric lamp.*

Apparatus:

Storage battery (or dry cells), a torch lamp of 2.5 volts fixed on a stand, a laboratory voltmeter, an ammeter, a switch and connecting wires.

Procedure:

1. Draw a circuit diagram of

the circuit with all its elements in your note book as shown in Fig. 6.3. Check up the fact that the ammeter and voltmeter are connected in series and parallel respectively with the lamp.

2. Arrange a circuit according to the circuit diagram drawn in your note book.

3. Put on the switch to make the current flow in the circuit.

4. Measure potential difference across the lamp with the help of the voltmeter.

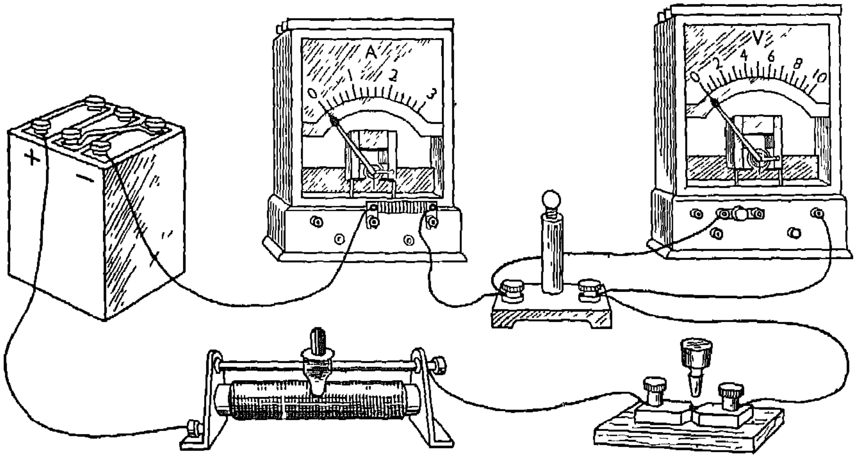


Fig 6.3. Circuit diagram for finding out the power consumed by a lamp.

5. Measure the strength of the current as indicated by the ammeter.

6. Calculate the power of the current and the work it does in 1 minute.

7. Compare the calculated power with that given on the envelope of the lamp.

EXERCISE

1. Find the work done by the current flowing for 5 minutes in a bulb if the bulb's voltage is 3.5 V and current used is 0 25 A.
2. An electric stove having a resistance of 24 ohms, is plugged into a 120 V circuit. Find the power of the current.
3. Find the current consumed by a 100 W lamp rated for 220 V.
4. The plate of an electric iron reads 220 V and 300 W Find its resistance
5. Examine the filament of 40 W and 200 W lamp rated for the same voltage 220. V. Which of the two filaments has the less resistance ? Substantiate your answer by making calculation,

6. There are 6 lamps in a house. Two of them are 100 W and two of 60 W and the rest are of 40 W. Calculate the cost of energy spent in one month (30 days) if each of them are used, on the average, for 5 hours daily and the energy is charged at the rate of 20 $\frac{\text{Paise}}{\text{k}W\text{h}}$

§ 68. Heating Effect of Electric Current

You have already known the different effects produced by electricity. One of them is its thermal effect. Let us find out the cause of heating of a conductor. It can be explained from the structure of metallic conductors. All its free electrons are in thermal chaotic motion. When we connect a metallic conductor to an electric source, the source produces an electric field in it. Under the influence of such a field, the electrons get directional motion. This directional motion is not free due to a lot of collisions with remaining parts of atoms. Due to such collisions, they receive more energy and move more rapidly. This increase in motion of the heavy particles leads to increase in the temperature of the conductor. So the flow of current through any conductor is associated with the production of heat in such conductor. Experience shows that a current produces heat not only in metallic conductors but also in liquid and gaseous conductors. In practice, we see that an electric current in different conductors produces different quantities of heat. Now let us find out how the heat produced by electric current in a conductor depends on the resistance of the conductor.

We have already seen that the work done W or any other energy produced in a resistor by any current is given as $W = 1 \times V \times t$ expressed in joules where I is expressed in ampere and V in Volts. We also know how to find out the quantity of heat in calories which is equivalent to that expressed in joules by the relation, 1 joule – 0.24 calories.

Hence, finally we get the relation,

$$Q = 0.24\ IVt \text{ calories.}$$

But in accordance with Ohm's law, V= IR. So the same formula can also be written as follows.

$$\begin{aligned} Q &= 0.24\ \text{I.V.t} \\ &= 0\ 24\ \ \text{I.I.R t} \\ &= 0.24\ \text{I}^2\text{.R.t.} \end{aligned}$$

In using this formula, if you know the strength of the current I in amperes, the resistance R in ohms, the time t in seconds the quantity of heat Q will be expressed in calories.

So, we can canclude that in cases where the same current flows in two different resistors for the same duration of time, the heat produced in each of resistors is proportional to their resistance.

§ 69. Laboratory Work No. 9

Aim: *To determine the value of ratio* $\frac{calorie}{joule}$.

Apparatus :

A 250-300 cc beaker, a thermometer, a 4 *V* battery, a heating coil of resistance 3 to 4 ohms, rheostat, ammeter, voltmeter, a watch, a switch, a balance and a set of weights, connecting wires and kerosene oil.

Procedure :

1. Draw the circuit diagram (Fig. 6.4) in your notebook and get it checked by your teacher.

2. Arrange the circuit according to your checked diagram and keep the switch in the off-position.

3. Weigh the beaker and the coil with the help of a balance.

4. Pour enough kerosene into the beaker to cover the coil as shown in Fig. 6.4 and again weigh the beaker and find the mass of the kerosene.

5. Note the initial temperature t°C of the kerosene with the help of a thermometer.

6. Switch on the current and note the time of switching on the current in your watch. It is best to switch the current when the second hand of the watch passes through the zero point.

7. Note the strength of current and the potential difference readings in the ammeter and voltmeter respectively. Be careful to have the current strength constant by adjusting your rheostat.

8. Switch off the current when the temperature of the kerosene has increased by about 6° and find out the time t of the passage of the current.

9. Measure the final temperature of the kerosene most accurately with the help of the thermometer.

10. Calculate the amount of heat Q, which heated the kerosene (specific heat of kerosene S 0.51) by using the formula:

$$Q = S \times m\,(t^\circ_2 - t^\circ_1).$$

11. Calculate the work done by the current during the time t by the formula, $W = I \times V \times t$.

12. Determine the ratio $\frac{Q}{W}$ and write down the results of measurement and calculations in the form as given below.

1. *Mass of beaker with coil,* m_1 (grammes) ...

2. *Mass of beaker with coil and kerosene*, m_2 (gramme) ...
3. *Mass of the kerosene*, $(m_2—m_1)=m$ (gramme) ...
4. *Initial temp. of the kerosene*, t_1°C ...
5. *Final temp of the kerosene* t_2°C ..
6. *Rise in temp. of the kerosene after passage of the current*, $(t_2°C—t_1°C)=t°C$ ...
7. *Quantity of heat supplied to the kerosene*, Q (cal) ...
8. *Current strength*, I (amp) ...
9. *Voltage*, V (volt) ...
10. *Time taken*, t ..
11. *Work done by current*, $(V \times I \times t)$ (joule) ...
12. *Value of the ratio*, $\frac{Q}{V \times I \times t}$ ...

§ 70. Electrical Heating Appliances

The thermal action of a current utilised in various electrical appliances. The most common are household electric bulbs, cooking ranges, irons, kettles, heaters etc. In industry, it is also utilised for smelting metals and also in electric welding. In agriculture too, it is used for fodder-steamers, hay drying, incubators and silomaking.

The basic component of an electrical heating appliance is its heating unit. Usually, it is a plate made of refractory material (mica, ceramics) on which wire or strip of metal with large specific resistance are wound. Usually, an alloy of nickel, chromium, iron and manganese, known as nichrome, is used for this purpose. Its specific resistance is 1.1 ohm $\frac{(mm)^2}{m}$ i. e., almost 70 times greater than that of copper.

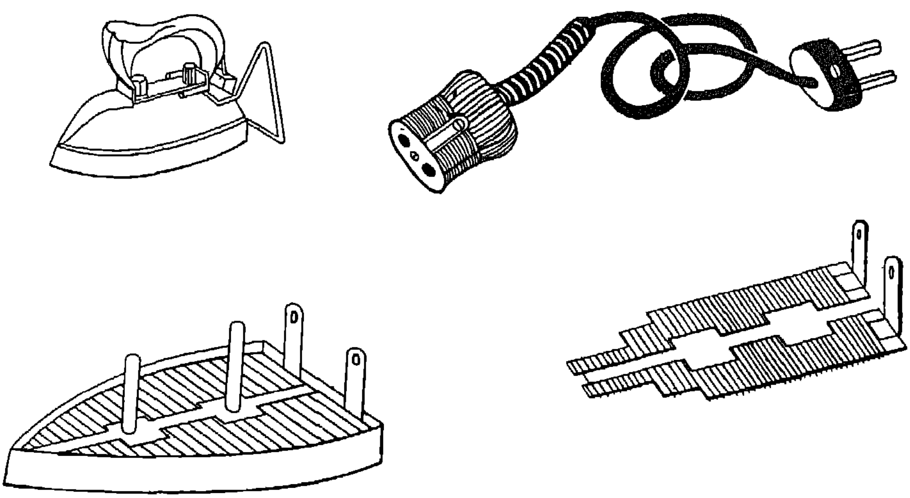


Fig 6.5. Electric iron and its different parts.

The heating unit of an electric iron is shown in Fig. 6.5. The current heats a nichrome strip up to 700°C. The strip conveys heat to the iron sole.

The design of an electric soldering iron is shown in Fig. 6.6.

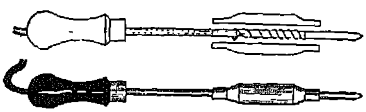


Fig. 6.6. Electric soldering iron.

The heating unit of an electric stove is a nichrome spiral arranged in a groove of ceramic plate (Fig. 6.7).

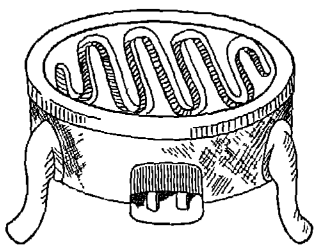


Fig 6 7. Electric stove.

Sometimes, a current is passed directly through substances in order to heat them. In some of the fodder-steamers, for instance, water is brought to a boiling point with the help of current passing through it from one electrode to the other. The same method is used in metallurgy in electrical smelting of iron, in refining aluminium, copper and other metals.

§ 71. Laboratory Work No. 10

Aim: To find the thermal efficiency of an electric heating coil.

Apparatus:

An ammeter, a voltmeter, a battery, a metallic coil, a vessel, a balance and a set of weights, a thermometer and a watch.

Procedure:

1. Draw the circuit diagram, as shown in Fig. 6.4, in your note book and get it checked by your teacher.

2. Pour some water in a vessel for boiling water. Take down the initial temperature of the water with the help of a thermometer.

3. Also determine the mass of the water taken in the vessel.

4. Now arrange the circuit according to the diagram in your note book. Plug in the electric heater's circuit and bring the water to the boiling point. Note the time to bring the water to its boiling point and also the boiling temperature of water.

5. Note the power of the heater as indicated in its certificate and calculate the work of the current in joules knowing the time taken by the heater to boil the water.

6. Also calculate the quantity of heat in calories expended for

heating the water to its boiling point by knowing its mass and difference of initial and boiling temperatures of the water. Find out the equivalent of this quantity of heat in joules.

7. Calculate the efficiency of the heater in percentage. Write down the results of measurements and calculation in your note book in the form as given below:

1. *Mass of the container*, m_1 (in grammes) ...
2. *Mass of container with water*, m_2 (in grammes) ...
3. *Initial temp. of water*, t_1°C ...
4. *Temp. of boiling of the water*, t_2°C ...
5. *Time taken by the heater to boil the water*, t (in seconds) .
6. *Current*, I (in amperes) ...
7. *Voltage across the coil*, V (in volts) ...
8. *Work done by the current*, $W_o = I \times V \times t$ (in joules) .
9. *Heat expended in boiling water*, $Q = (m_2 - m_1)\ (t_2°C - t_1°C)$ (in calories) . .
10. *Work equivalent to the heat produced* ($W_H = Q \times 4\ 18$) (in joules) ...
11. *Efficiency*, $\frac{W_H}{W_o} \times 100$ ...

EXERCISE

1. What quantity of heat will be produced in a coil of resistance 40 ohms if 3A current is passed through it for 5 minutes
2. The resistance of one electric lamp is twice as great as the other. Which of the two produces greater quantity of heat in the same time and by how much.
3. Heat is generated continuously in an electric iron but their temperature does not increase infinitely. Why ?
4. An electric soldering iron takes power of 30W from the mains. Find the amount of heat produced by it in an hour.
5. An electric metal smelting furnace takes 8,000A from a 60V line Calculate the quantity of heat it produces in one minute.

§ 72. The Incandescent Lamp

You are familiar with electric lamps. You see them in the streets and in your own houses. They are not of the same type as they were, when invented first.

The first attempt to have an incandescent lamp for practical use was made in the 19th century. In the beginning, a small carbon filament of about 3 mm diameter was fixed between two copper conductors. They were enclosed in a glass envelope (Fig. 6.8).

The glass envelope was evacuated

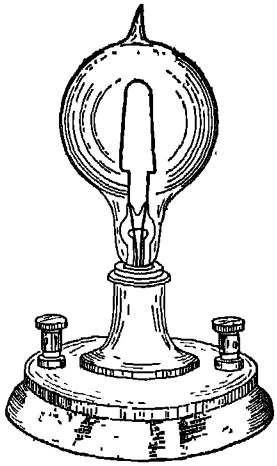


Fig. 6.8 Carbon filament electric bulb.

to protect the carbon from burning. As the perfect vacuum was impossible to achieve at that time, these lamps were short-lived. To overcome this difficulty, metal filaments of high melting point (such as tungsten, molybdenum, osmium) were used in place of carbon filaments. Such lamps with metal filaments were further improved by Thomas Edison. In particular, he suggested providing lamps with a screw type base and invented the lamp holder, for it the switch and other elements of the lighting network.

The filaments of incandescent lamps are nowadays twisted spirals of tungsten. The melting point of tungsten being 3300°C, it can be heated to 3000°C. However, at this temperature, tungsten begins to evaporate rapidly and so the filament becomes gradually thinner until it finally burns through. To prevent this rapid evaporation of the tungsten filament nowadays these lamps are filled with an inert gas such as argon or krypton. The gas lengthens the life and light-producing ability of the lamp. The high resistance of the tungsten filament causes it to become very hot and gives off a white glow. Incandescent lamps are usually manufactured in a variety of sizes and shapes. The most popular sizes for domestic use are 25, 40, 60, 100 and 150 watts. The most commonly used base is the type with two protruding pins (Fig. 6.9).

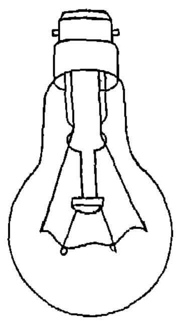


Fig. 6.9 Gas filled incandescent lamp.

Fig. 6.9 illustrates a gas-filled incandescent lamp. The ends of the filament in it are soldered to the two thick wires passing through the bulb and soldered to the metal base but insulated from the base proper.

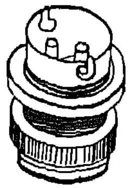


Fig. 6.10. Domestic bulb holder.

To put a lamp in the circuit, it is pushed in the holder (Fig. 6.10) and turned. By doing so, the bulb is locked into the socket by the two pins. To remove the lamp, the glass bulb is pushed in and turned until the two pins come out of the socket slots.

Industry manufactures incandescent lamps bearing two specifications (*i*) the voltage and (*ii*) the wattage. Some of them are operated on different voltages such as 220 *V* (for lighting networks), 50 *V* (for railway carriages), 12 *V* and 6 *V* (for motor cars), 3.5 and 2.5 (for pocket torches). The lamps operated on the same voltage are classified according to their wattage (power), for example, the bulbs used in our houses are all operated on 220 *V* but have different powers (15 W, 25 W, 40 W, 60 W, 100 W).

§ 73. Electric Fuses

When a house is wired for the supply of electrical energy, the wiring is made of copper wire of low resistance covered with an insulating material. These wires are rated for a definite maximum current. If the current exceeds, the wires get heated and their insulation may ignite. As the cable is usually built into steel pipes in the wall or under the floor, repair is difficult and costly. A weak point is, therefore, built into the circuit which is accessible, and is known as a fuse. So the fuse acts as a safety valve in the electrical circuit. The fuse will blow off before any of the copper cable in the circuit gets hot.

The reason for the surges of current in the network may be either due to simultaneous connection to it of a number of powerful consumers such as electric range or as a result of a so-called short-circuit. A short-circuit is a direct connection of wires rather than via a device possessing the required resistance. The connection may occur due to a damaged insulation of wires. Since their resistance is rather negligible, the current-surges in the circuit reach hundred of amperes. So the purpose of a fuse is to break the line, the moment an excessive current appears in the network and thus eliminates the fire hazards. Fuse wire is made of an alloy of lead and tin of low melting point. It is manufactured in different diameters to be used in lighting, power, or other circuits,

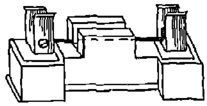


Fig. 6.11. Domestic fuse holder.

The diagram of a fuse carrier with a fuse wire used in an average domestic electrical system is shown in Fig. 6.11. It is easily removable from its socket. These carriers are used with 5, 10, 15 or 30 ampere fuse wires.

Fuse wire wrapped on a cardboard is sold in small quantities for domestic use. To wire a fuse properly, one loose end of the fuse wire is wrapped around the bolt and in the direction of tightening the bolt. The bolt is then tightened securely. A small portion of the fuse wire is then unwrapped from the carrier board and after straightening is wrapped again around the second bolt as in the previous case. Finally, the wire is broken off from the cardboard near the second bolt. Now the fuse carrier is ready for use.

Magnetism and Electro-magnetic Phenomenon

§ 74. History of the Discovery of Magnets

The word *magnetism* comes from Magnesia, the name of a region in ancient Asia Minor. In this region such stones were found which would cling to the iron tips of the staffs of the inhabitants. Later on these stones were found to contain some iron ore which was responsible for attracting the iron tips. These ores (Fig. 7.1) were named *magnetite* after the name of the region that is why we speak of magnetism today.

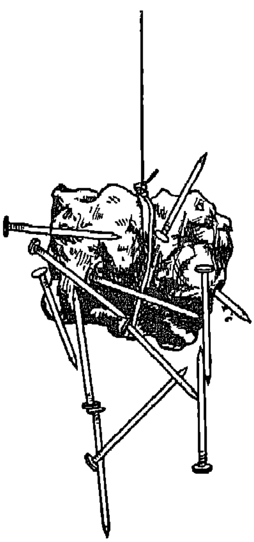


Fig. 7.1. Magnetite attracting iron nails.

Later, these stones containing magnetite were found to have directional property also. When any of it was suspended freely, a particular tip of the stone at rest always pointed to northerly direction. Due to this directional property such stones were called *loadstone* meaning leading stone. Whenever any iron piece is rubbed several times in the same direction with a loadstone, the iron piece acquires both the properties of the loadstone, i.e., (1) the property of attracting iron and other like substances and (2) property of pointing to the north direction. Such a metallic piece, possessing both these properties, is known as *magnet*.

§ 75. Specific Features of Magnets

We have seen that a piece of magnetite which is a natural ore is a magnet. Such magnets which are found in nature are called *natural magnets*. On the other hand, some magnets are also made out artificially, for example by rubbing iron pieces with loadstone. Such artifi-

cially made magnets are called *artificial magnets.* Magnets are made of different materials and have different shapes.

Some magnets get their names from their shapes. A straight magnet is called a *bar magnet*, one shaped like the horse-shoe is called a *horse-shoe magnet* (Fig. 7.2).

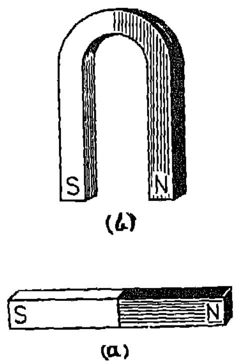


Fig. 7.2. (*a*) Bar magnet;
(*b*) Horse shoe magnet.

Magnets are usually made of steel. Some magnets are also made of an alloy of aluminium, nickel and cobalt instead. To know some important features of a magnet, perform the following experiments.

Poles of a magnet.

Place a bar magnet on a thin layer of iron filings. By raising the bar magnet you will see that the iron filings cling to it in an irregular fashion. Most of them stick to the bar's ends but only a few of them cling to the middle portion of the magnet (Fig. 7.3).

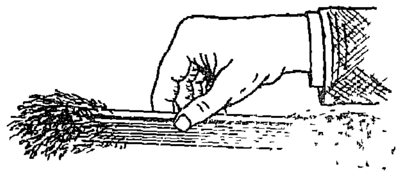


Fig 7.3 Iron filings sticking mostly to the ends of a bar magnet

The two places on a magnet which attract more filings are called *poles* of the magnet. So we conclude,

(*a*) Magnets have an attractive property.

(*b*) Attractive properties are more intense near the poles of a magnet but very feeble in the middle portion of the magnet.

Experiment to show the directional property of a magnet:

Now suspend a bar magnet with an unspun silk thread as shown in Fig. 7.4. After a few swings it will settle down with its one pole pointing towards the north and the other towards the south. So, we see that a magnet possesses another important property. This property is known as *directional property.* The north pointing end of the magnet is known as *north pole* marked by the letter *N* and the south pointing

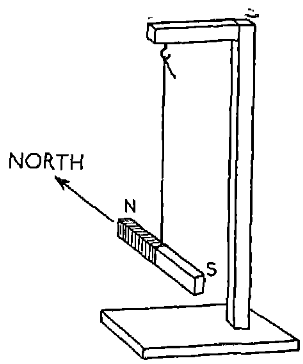


Fig. 7.4. The ends of a freely suspended bar magnet point to north and south directions.

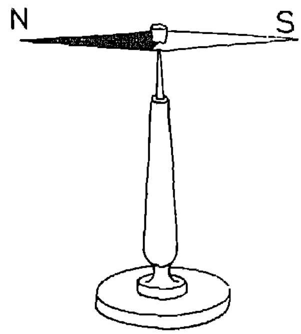


Fig. 7.5. Magnetic needle mounted on a stand.

end is known as *south pole* indicated by the letter *S*.

Any magnet has at least one north and one south pole.

§ 76. Interaction of Magnets

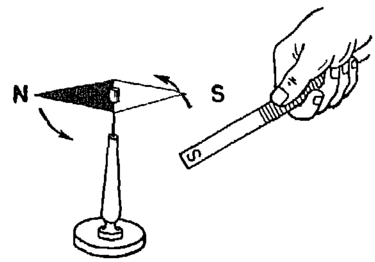


Fig. 7.6. Interaction between a magnetic needle and a bar magnet.

The action of a magnet upon another magnet is known as *magnetic interaction*. Such interaction of magnets can be seen with the help of either a magnetic needle and a magnet or a pair of bar magnets.

Take two bar magnets, one suspended freely from an unspun silk thread. Hold the second magnet in your hand and bring its north pole near the north pole of the suspended magnet. You will see that the *N* pole of the suspended magnet is repelled. If on the other hand, you bring the south pole of the magnet in your hand near the north pole of the suspended magnet, the *N* pole of the suspended magnet will be found to be attracted to the *S* pole of the magnet in hand (Fig. 7.7).

So we conclude that like magnetic poles repel and unlike poles attract each other.

The interaction of a magnetic needle with another magnet can be used in determining the poles of a magnet. Bring the tip of a magnet to the north pole of the magnetic

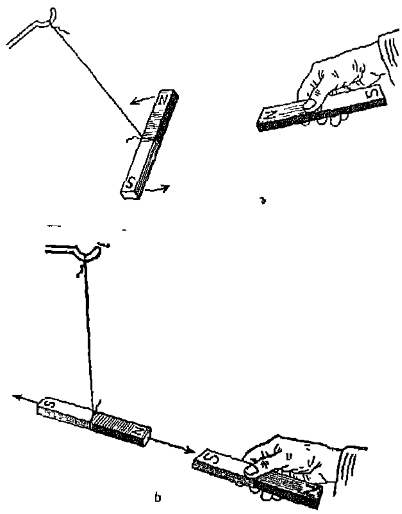


Fig. 7.7. Interaction between a freely suspended bar magnet and another bar magnet

needle. If the north pole of the needle is attracted towards the tip of the magnet, that tip of the magnet is south pole and the other end is north pole. In the reverse case, the end brought near the needle is north pole and the other end is south pole.

§ 77. Magnetic Field

You have already learnt that when a magnetic needle is brought near a magnet, the pole of the needle is either deflected away or attracted. If you remove the magnet altogether, the needle comes to rest in north-south direction. How can we explain this interaction between a magnet and a magnetic needle when they are apart by a certain distance ? While studying electric phenomena you have learnt that two electric charges separated by a certain distance interact. This phenomenon was explained with the help of electric field which exists around any electric charge.

From the analogy with electric phenomena, it appears that magnets interact through magnetic field. The magnetic field is produced by any magnet in the space surrounding it. Like an electric field, the presence of any magnetic field is not felt with the help of our senses. It can be detected only by the action of the magnetic field upon a magnetic needle brought in the field. Therefore, for recognising the existence of a magnetic field at a particular point of the space, a magnetic needle must be placed at this point. If the needle is deflected from its normal north-south direction, it means that there is some force acting upon the needle. This force is produced by the action of the magnetic field of the magnet. If you bring the magnetic needle closer and closer to the magnet, the deflection or attraction of the magnetic needle increases. If you remove the magnetic needle further and further from the magnet, the attraction or deflection decreases. From this experiment you can draw the conclusion that a magnetic field exists at all points around the mag-

net (Fig. 7.8, *a*) and the strength of the magnetic field at a point depends

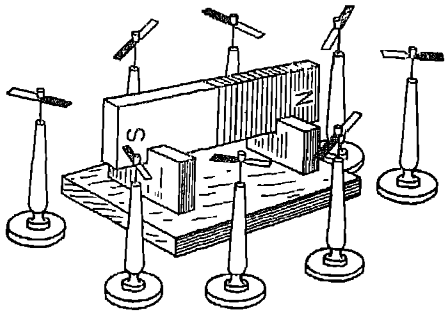


Fig 7.8 (*a*). Magnetic field at some points in the space surrounding a magnet.

on its distance from the magnet, decreasing with the increase of distance of the point from the magnet and vice versa (Fig. 7.8, *b*)

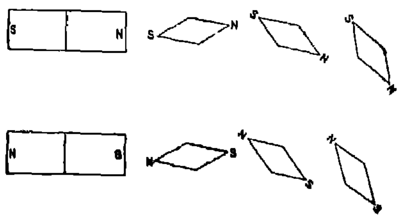


Fig. 7.8 (*b*). Strength of the field at a point varies according to the distance of the point from the magnet.

§ 78. Magnetization by Induction

Whenever a body made of soft steel is placed in a magentic field, it becomes magnetized and starts attracting other magnetic materials (Fig. 7.9). Such magnetization of the magnetic material due to its placement in the magnetic field is

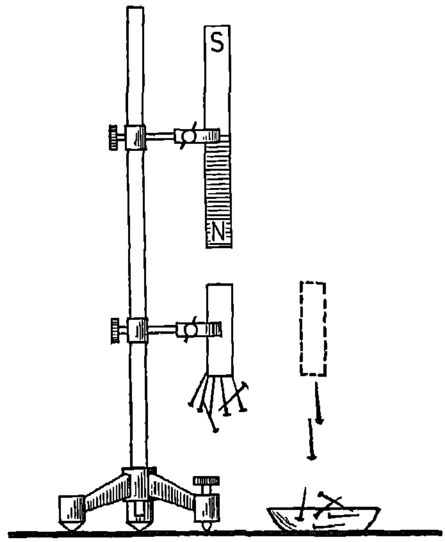


Fig. 7.9. Magnetization by magnetic induction—an iron rod placed near a magnet becomes magnetized

known as *magnetization by magnetic induction.* If you remove magnet producing the magnetic field, the magnetization of such material disappears simultaneously.

Now let us find out the other characteristics of such magnetized materials. For this, let us take a bar magnet (for producing magnetic field), an iron bar and a magnetic needle. Place the magnet with its *N* pole towards one end of the iron bar and close to it (Fig. 7.10). Bring the magnetic needle near the other end of the iron bar. You will observe that the *S* pole of the needle is attracted (Fig. 7.10, *a*). It means that the far end of the iron bar

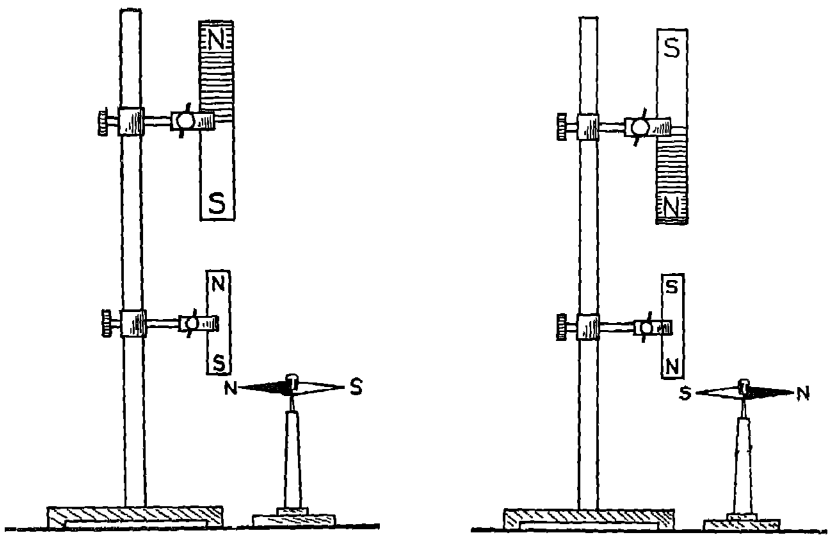
possesses the *N* polarity. Now try with a second iron bar. The same thing will be found again.

Now repeat the experiment with a different iron bar but this time with the *S* pole of the magnet near the end of the iron bar. Bring the magnetic needle again near the far end of the iron bar. This time you will find that *N* pole of the needle is attracted (Fig 7.10, *b*). So we conclude that the far end of the iron bar always develops the polarity similar to that of the nearer end of the magnet and so the nearer end of the iron bar will naturally be having opposite polarity.

Here you see that the iron bar is not in direct touch with the magnet but still it gets magnetized because of its placement in the magnetic field of the magnet. So we can conclude that the magnetization by magnetic induction has the following features.

(*i*) Magnetization by induction is due to the presence of a magnetic field.

(*ii*) The nearer end of the magnetized material develops the opposite polarity and the far end the similar polarity to that of the nearer end of the magnet causing the magnetic field.



(*a*) (*b*)

Fig. 7.10. Nature of polarity of an iron rod due to magnetic induction.

§ 79. Magnetic Lines of Force

You have learnt that any magnet

produces a magnetic field around it. The shape of the magnet influences the specific feature of the magnetic field of a magnet. It can be seen with the following experiments.

Place six or eight magnetic needles around a bar magnet symmetrically as shown in Fig. 7.11. Observe the

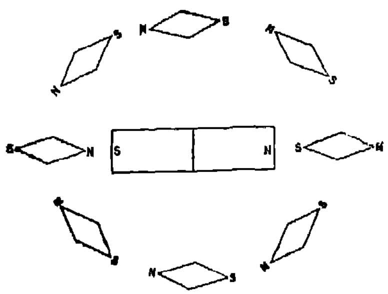


Fig 7.11 Magnetic needles, placed at different points around a magnet, point in different directions

direction of each of the needles. You will find that each of them is pointing in a different direction. It means that the directions of the magnetic force at different points of the magnetic field are different. It is a commonly accepted convention that the direction of the magnetic force is the direction indicated by the north pole of the needle. The lines of magnetic force can be obtained with the help of iron filings as follows.

Sprinkle some iron filings upon a glass plate or a piece of cardboard, and put the plate upon a bar magnet kept on a table. Now, gently tap the plate. By doing so you will notice that the iron filings arrange themselves in an orderly curved lines running from one pole to the other as shown in Fig. 7.12.

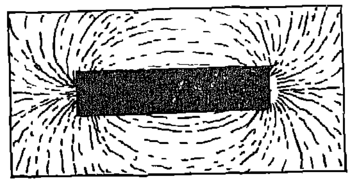


Fig. 7.12. Pattern formed by the iron filings spread over, in the magnetic field of a bar magnet.

Now repeat the experiment in the same way using two bar magnets. First arrange the magnets with their opposite poles adjacent to each other and 3 or 4 cm apart. Again tap the plate and notice the pattern formed by iron filings. It is similar to that shown in Fig. 7.13.

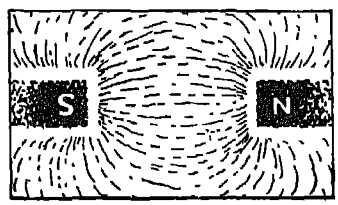


Fig. 7.13. Magnetic field of two unlike poles facing each other.

Next arrange the magnets with their *N* poles close to each other. On tapping the plate, you will find

the pattern formed by iron filings as shown in Fig. 7.14.

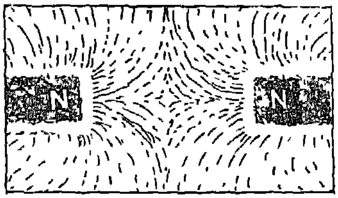


Fig. 7.14. Magnetic field of two like poles facing each other.

From the above experiments it seems that each tiny particle of iron indicates the direction of the magnetic force. This is because the tiny pieces of iron become magnetized under the influence of the magnetic field of the magnet under the plate and then set themselves along the lines of the magnetic force. On further examination, the pattern of iron filings around a single bar magnet, shows that the magnetic field around a magnet is continuous. It is strong at the poles but gradually weakens as the distance from the poles increases. This is evident from the fact that the lines are closest together at the poles and apart in the rest of the regions.

You have already learnt that the direction of a line of force is the direction indicated by the north magnetic pole. As such, with the help of a magnetic needle we notice that the lines of force of a magnetic field due to a magnet are directed from the north pole to the south pole of the magnet. The direction of the lines of force of a bar magnet and those of a horse-shoe magnet are shown in Fig. 7.15.

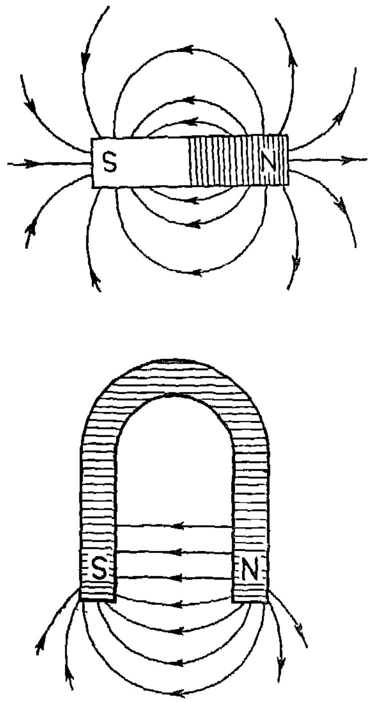


Fig. 7.15. Lines of force in the fields of a bar magnet and a horse-shoe magnet

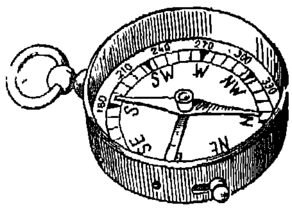
§ 10. Compass and the magnetic field of the earth

Finding your way in a village or a town is easy. But it would be difficult to find your way through thick forests. There, thousands of trees look alike. There is not much to guide you, You would have still

more difficulty on the ocean or far above in the sky. Out of sight of land, there is almost nothing to guide you. Yet you know that explorers find directions in dense jungles, sailors and aviators across the trackless oceans and long distances in the sky without difficulty. Do you know how they are guided in their directions?

They are all guided by compasses to help them and steer their ships and airplanes in the right direction. Woodmen and hunters carry compasses to use them. Now let us see the components of a compass and the way they are used.

The main component of the compass is a magnetic needle fixed on a pin-point (Fig. 7.16). To protect



Compass.

Fig. 7.16

it from blunting, the compass is provided with a catch which locks the needle in the upper position when not in use. The compass is also provided with a circular scale below the needle. The axis of the needle passes through the centre of this circular scale. All these components are enclosed in a case having a glass cover. The scale has all the cardinal points marked on it. They can be found by releasing the needle and turning the compass so that the point of the scale corresponding to the north direction coincides with the north tip of the needle. While adjusting the compass for correct orientation, one should be careful to remove all iron and steel objects near the compass. The presence of such objects causes deflection of the needle of the compass and thus makes it to give incorrect reading.

You have seen that the needle of a compass always points approximately north and south. You can turn the case of the compass any way, but the needle still points in the same north-south direction. One end of the needle here always points northward.

Now, if the compass is placed at different places on the earth, as well as a little above the earth, it is found that the needle of a compass points differently at these different points. You have also seen that a magnetic needle points differently when placed at different points of the magnetic field of a magnet. So, we can say that a magnetic field is present everywhere surrounding the earth. This magnetic field acts

upon the compass needle and makes it align along the lines of force of the magnetic field of the earth.

Fig. 7.17 gives a schematic diagram of the magnetic field around the

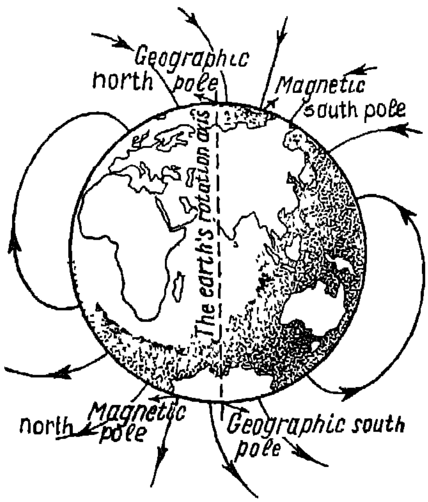


Fig. 7 17. Schematic diagram of the magnetic field around the earth.

earth. These lines of force have been obtained with the help of a compass. It looks as if the earth acts like a huge magnet with two poles. You know that dissimilar poles are attracted to each other. Keeping this in mind when you also see that the north pole of a compass needle or a freely suspended magnet points to the north, it means that the south pole of the earth's magnet is situated near the geographical north of the earth and the north pole near the geographical south of it. These two poles of the earth are known as the *geomagnetic poles* (two points of the earth which are near the geographic poles). It is to be noted here that the geomagnetic north-south direction does not coincide with the geographic north-south direction.

§ 81. Laboratory Work No. 11

Aim·

To study the properties of a magnet and to obtain the distribution of the lines of a force of its magnetic fields.

Apparatus·

Two bar magnets, a magnetized needle, iron filings, bits of soft iron nails, a piece of cardboard and a razor blade, one piece each of aluminium, glass, rubber, paper and steel.

Procedure:

1. Check which of the following objects—steel, iron rods, rubber, glass, aluminium, and paper—are attracted by a magnet and put them under two heads,

(*i*) magnetic, and

(*ii*) non-magnetic substances.

2. Show those parts of a magnet to which iron filings are attracted strongly.

3. Suspend iron nails in a chain from a pole of the magnet. Take hold of the uppermost nail in the chain and carefully remove the magnet. See whether the chain is preserved or not.

4. Suspend a razor blade from one pole of the magnet. Now check with the help of a magnetized needle whether the blade is magnetized or not.

5. Place a bar magnet on the table and cover it with a piece of cardboard. Spread some iron filings in a thin layer on it. Now tap the cardboard lightly with your finger. Examine the paths along which iron filings get aligned. These paths represent the lines of force. Draw the distribution of lines of force in your note book.

6. Keep two bar magnets with their like poles facing each other on a table. Cover them with a cardboard having iron filings spread over it in a thin layer. Tap the cardboard gently. Examine the distribution of the lines of force of the resultant magnetic field of the magnets and draw them in your note book.

7. Repeat the above experiment with S pole of one magnet facing the N pole of the other and draw the lines of force of the resultant magnetic field in this case.

§ 82. The Action of a Current on a Magnetized Needle

Up to the end of 18th century, it was thought that magnetic and electric effects were entirely different and there was no relationship between them. However, in 1819, a Danish scientist Oersted made a most important discovery that when a magnetic needle is brought in the neighbourhood of a current bearing wire, it is deflected. In other words, this discovery established the fact that:

An electric current produces a magnetic field around it.

To show the above effect, perform the following experiment.

Connect a piece of ordinary insulated wire through a switch to a battery of three dry cells connected in series as shown in Fig. 7.18. Hold

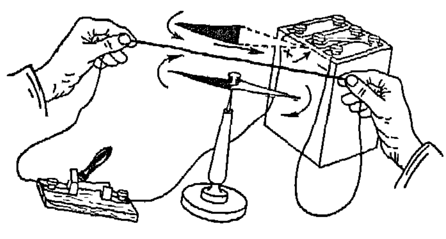


Fig. 7.18. Illustration of Oersted experiment.

a portion of this wire parallel to and above a magnet needle at rest. Close the switch and you will notice that the magnetic needle is deflected through an angle. When the switch

is opened, the needle comes to its original position in north-south direction indicating thereby the absence of any magnetic field other than that of the earth.

The deflection of the needle by the electric current indicates that there exists a magnetic field around the wire as long as the current is flowing in the conductor.

So it is important to note here that there are two sources of magnetic field:

(*i*) a permanent magnet of any shape, and

(*ii*) an electric current passing through a conductor.

Now repeat the experiment with the only difference that the wire is placed below the magnetic needle but keeping the direction of current in the wire unchanged. When the switch is closed, the magnetic needle is again deflected at an angle but this time in opposite direction. So we see that the directions of the lines of force of the magnetic field of a current at two points one above and the other below the current carrying conductor are opposite to each other.

Now, to know the exact direction of the lines of force of the magnetic field about a current, let us perform the following experiment.

Run a heavy copper wire through the centre of a piece of cardboard supported horizontally. Connect the ends of this wire to a battery of at least 6 dry cells through a switch. Sprinkle iron filings on the cardboard near the wire and close the switch. Tap the cardboard gently. You will notice that the iron filings arrange themselves in concentric circles with their centre at the wire [(Fig. 7.19 (*a*)).]

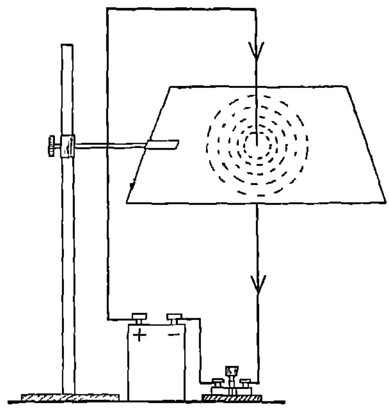


Fig. 7.19 (*a*). Iron filings, spread around a current bearing conductor, get arranged in concentric circles with their centre at the axis of the wire.

Now, place three or four small compass needles on the cardboard as shown in Fig. 7.19 (*b*). The compasses turn and set themselves along the paths of the circular lines of force.

Finally, reverse the direction of the current in the wire and observe

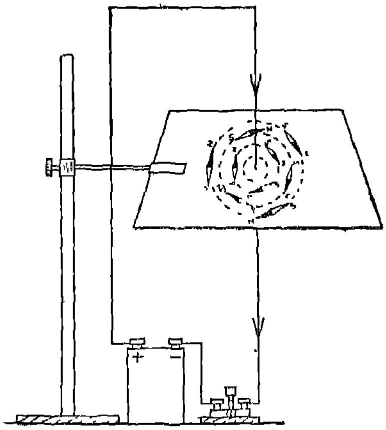


Fig. 7.19 (*b*). Direction of the magnetic field around a current flowing in the downward direction.

its effect on the magnetic needle. This time the compasses are deflected but in the opposite direction [Fig. 7.19 (*c*)].

The above experiment proves

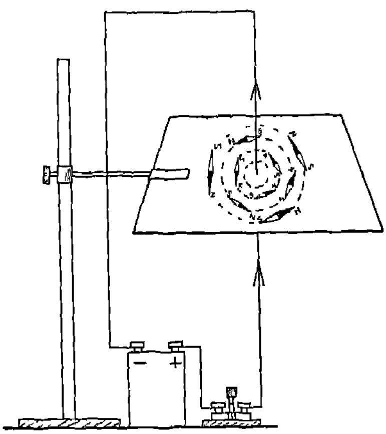


Fig. 7.19 (*c*). Direction of the magnetic field around a current flowing in the upward direction.

that the magnetic field due to a current consists of a series of concentric lines of force with the current bearing wire passing through their centres and also that the direction of these magnetic lines of force depends upon the direction of current flowing in the wire.

There is a convenient way to remember the direction of the lines of magnetic force due to a current flowing in a particular direction. This is known as *thumb-rule* which states: *If the wire is held with the left hand in such a way that the thumb points to the direction of the flow of electrons (opposite to that of the conventional current) in the wire, then the tips of the fingers encircling the wire point to the direction of magnetic lines of force, that is, the direction in which the N-pole of compass needle would point* (Fig. 7.20).

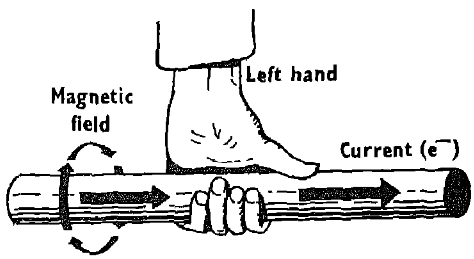


Fig. 7.20. Illustration for 'Thumb rule.'

§ 83. The Magnetic Field of a Solenoid

You have learnt that current bearing coil behaves like a magnet.

This coil is known as a *solenoid* (Fig. 7.21 *a*, *b*).

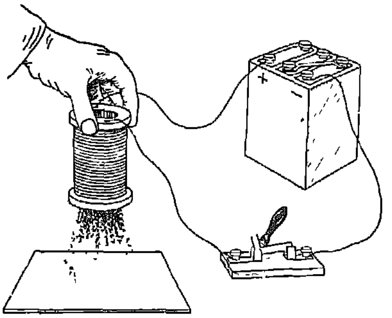


Fig. 7.21 (*a*). Iron filings are being attracted by a current carrying solenoid.

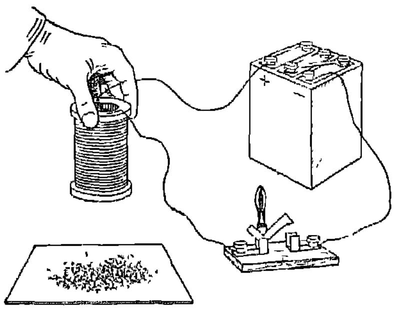


Fig. 7 21 (*b*). Iron filings fall off as soon as the current stops flowing in the solenoid.

Such coils possess two magnetic poles as long as the current is flowing through the solenoid. The polarity of this current carrying solenoid can be detected by placing two magnetic needles, one at each of the two ends of the solenoid as shown in Fig. 7.22. By doing so, you will observe that one of the needles turns towards the current carrying sole-

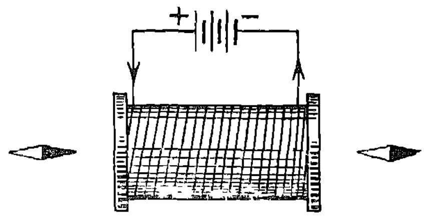


Fig. 7.22. Finding out the nature of polarity of a solenoid with the help of a magnetic needle.

noid with its north tip, while the other one with its south tip. This confirms that one end of the current bearing solenoid has south polarity and the other has north polarity.

Now let us find out the specific feature of the lines of force of the magnetic field around a current carrying solenoid. For this, perform the following experiment.

Arrange the device as shown in Fig. 7.23. Here the turns of the

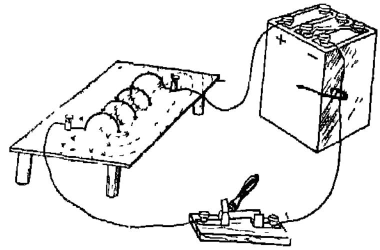


Fig. 7.23. Magnetic field of a current bearing coil.

solenoid are passed through the top of a cardboard table. Spread some iron filings on the cardboard. Connect the solenoid to a battery

of dry *cells* and tap the table lightly. The filings are arranged along the lines of force of the magnetic field of the solenoid. The distribution of the magnetic lines of force demonstrates that the magnetic field of the solenoid is very much like that of a bar magnet. It also shows that there is a field inside the coil too and the lines of force of the magnetic field are closed. Also determine the poles of the coil with the help of a magnetized needle. You will find that outside the solenoid the lines of force emerge from the north pole of the solenoid and enter its south pole.

§ 84. Electromagnet

The solenoid with an iron core is called an *electromagnet.* The reason for using iron core in the solenoid can be understood with the experiment given below.

Make a solenoid upon a cardboard cylinder. Take this solenoid and connect it to a battery of cells through a rheostat and a switch as shown in Fig. 7.24. Place a magnetized needle at some distance from one end of the solenoid. Switch on the current. The magnetic needle will be deflected at a certain angle. Switch off the current and insert an iron nail in the cardboard tube. Again switch on the current and

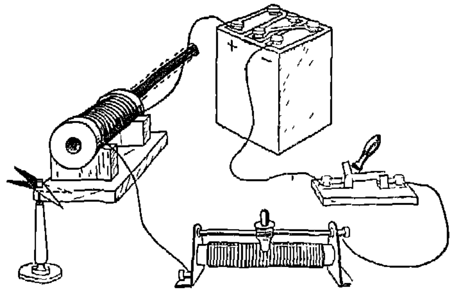


Fig. 7 24 Influence of the iron rod, used as core of the solenoid, on its magnetic field.

observe the deflection of the magnetic needle. This time the needle will be deflected more than in the previous case. So it proves that the purpose of the iron core is to intensify the magnetic field of the solenoid. Such a solenoid with an iron core acquires all the properties of a magnet as long as the current flows in it. When the current ceases to flow the magnetic properties of the electromagnet disappear. Now let us find out the effect of the number of turns and the strength of the current upon the strength of the magnetic field of an electromagnet. For this, perform the following experiment.

Experiment to show the effect of the number of turns in the electromagnet on the strength of its magnetic field.

Make a coil of 20 turns of an insulated copper wire around a large iron nail. This will be our electro-

magnet. Connect the ends of the electromagnet to a storage battery through an ammeter and a rheostat as shown in Fig. 7.25. Bring some

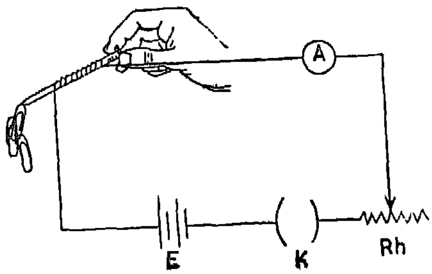


Fig 7 25. Paper clips are attracted to an electromagnet.

paper clips near one end of the electromagnet. Switch on the current and adjust it to a strength of 1 ampere with the help of the rheostat.

By doing so, we see that some clips are attracted to the end of the electromagnet. Count their numbers.

Repeat the experiment with a coil of 40 turns of the same copper wire over the same nail. This time, the resistance of coils is twice that of the former coil. To keep the current equal to 1 ampere as in the previous experiment, adjust the rheostat and find out how many of the clips are attracted this time. You will see that the *number is more than* that in the previous experiment. So we conclude that the strength of the magnetic field of the electromagnet increases with the increase in the number of turns of the coils provided the current is kept constant.

Experiment on dependence of magnetic field of an electromagnet upon the value of the current

Now, repeat the experiment with an electromagnet of 20 turns. Adjust the strength of the current to 2 amperes. Find out the number of clips attracted to the electromagnet. You will find that the *number of* clips are more than those in the case of 1 ampere current passing through the same coil of the electromagnet. So, we conclude that

The strength of the magnetic field increases with the increase of the current flowing through the coil of an electromagnet and vice versa.

So, finally we see that the strength of the magnetic field of an electromagnet depends upon

(*i*) the number of turns in the coil, and

(*ii*) the current in the coil in the manner indicated above.

We have seen that an electromagnet can be made from a soft iron nail or rod by winding it with a few turns of insulated wire. Here the nail or rod used is called the *core* of the electromagnet. A steel rod

can also be used for core. When we compare the effectiveness of steel and soft iron core in an electromagnet, we see that field is stronger in case of iron core. But steel retains a small amount of magnetism even when the current has ceased to flow in the coil of the electromagnet whereas, in the case of soft iron core, the magnetism disappears altogether as soon as the current ceases to flow in the coil of the electromagnet.

Electromagnets have different shapes depending on their purpose. Fig. 7.26 shows a horse shoe electro-

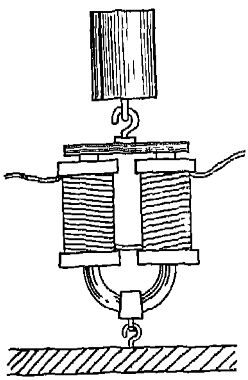


Fig. 7.26. Horse-shoe electromagnet lifting a weight.

magnet holding a weight suspended from it. The horse shoe electromagnet possesses more lifting force than a bar electromagnet, because it attracts by its two poles simultaneously.

Powerful electromagnets are used in factories for lifting and carrying heavy iron and steel parts, ingots, iron scrapes, filings etc. (Fig. 7.27).

Fig. 7.27. A powerful electromagnet being used in a factory to lift heavy ingots of 1000 kg each.

Electromagnets are also used when iron ore is to be separated from rocks in iron ore mines (Fig. 7.28).

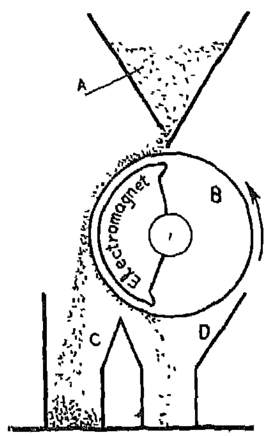


Fig. 7.28. Magnetic ore separator.

§ 85. Laboratory Work No. 12

Aim :

To assemble and test an electromagnet.

Apparatus :

A storage battery, a switch, 2 metres of insulated copper wire, a compass needle, an ammeter, a rheostat, iron nails, connecting wire etc.

Procedure :

1. Wind several turns of a copper wire around a *tubular cardboard cylinder* and arrange a circuit as shown in Fig. 7.24.

2. Place the compass needle near one of the solenoid. Note the direction of the needle.

3. Switch on the current and observe the deflection of the needle.

4. Make sure that the ends of a solenoid develop opposite magnetic polarity each time the current is passed through it.

5. Reverse the direction of the current in the coil and find its effect on the reversal of the polarity at the two ends of the solenoid.

6. Insert an iron nail into the cardboard tube and find out whether it increases the interaction of the solenoid on the magnetic needle.

7. Now keeping the number of turns in an electromagnet unchanged, vary (increase or decrease) the strength of the current with the help of a rheostat and find out its effect on the deflection of the magnetic needle.

8. Vary (increase or decrease) the number of turns in the electromagnet but each time keep the same strength of the current as in the previous case by adjusting the rheostat and find out its effect on the deflection of the needle.

9. Assemble a horse-shoe magnet from the ready made parts. Make sure that the coils on its two arms are wound in opposite directions. Check the results experimentally.

EXERCISE

1. How can you determine the poles of a magnet if they are not indicated ? Describe all the methods you know.
2. A magnetic needle is attracted to a steel knitting needle with both its poles. What can you say about the magnetisation of the knitting needle ?
3. One of the two similar steel knitting needles is magnetised. How can you find which of the two is magnetised, if there are no other objects at hand ?

4. Why two chains formed of iron filings attracted to the pole of a magnet, repel each other at the other end ?
5. If a magnet is brought close to two razor blades suspended with threads, they begin to repel each other. Explain the reasons
6. In what ways a current carrying solenoid and a bar magnet are similar ?
7. Distinguish between a permanent magnet and an electromagnet.
8. What are the factors which affect the strength of an electromagnet ?
9. Why are most electromagnets made in U shape ?

§ 86. The Electric Door-Bell

The electric door-bell shown in Fig. 7.29 has a horse-shoe electro-

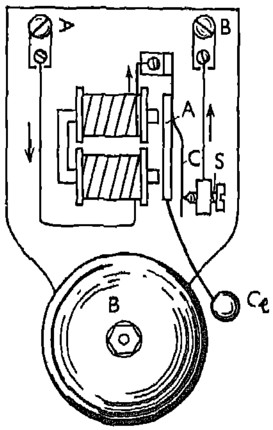


Fig. 7.29. Electric door-bell.

magnet and a soft iron armature. *A*. The armature has a clapper *Cl* for striking the bell *B* and a contact spring *C* which remains in contact with a screw *S*. In the electric door-bell, the clapper is made to strike the bell repeatedly. This is achieved by making the armature vibrate rapidly. Now let us understand how and why the armature keeps vibrating as detailed below. When the button of the door bell is pressed, the current flows via the electromagnet winding, the armature, the contact spring and the screw. The flow of current in the winding magnetizes the iron core of the electromagnet. The magnetized core then attracts the armature causing the attached clapper to strike the metal bell. As the diagram shows, with forward movement of the armature due to magnetic attraction, the contact spring moves away from the screw and thus the circuit is broken. As a result of the break of circuit, the current ceases to flow in the electromagnet winding and consequently the core loses its magnetism. It, therefore, no longer attracts the armature which then is pulled back by the contact spring to its original position. When this happens, contact with the screw is again made so that the circuit is completed again. The coil is thus again magnetised, draws the armature and another cycle begins. As long as the door bell is connected to a power source,

the circuit is alternately broken and made automatically and the armature actuated by the coil vibrates and the clapper strikes the bell. Thus the door bell keeps ringing.

Special button-switches used in door bell circuits (Fig. 7.30) consist

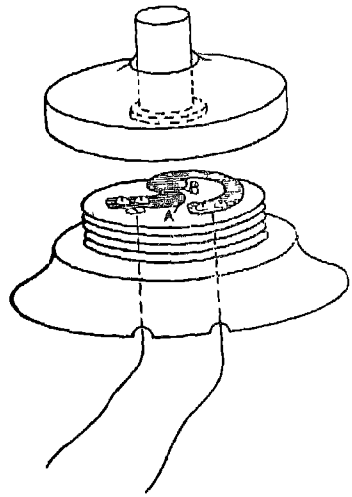


Fig. 7.30. Push button switch used in electric door bell.

of the fixed contact A and a spring contact B which are usually open. When the button is pressed, the contacts close and the door bell starts ringing.

Electric bells are used in automatic signalling systems, in industry, railways, in fire alarm and houses.

§ 87. Electric Telegraph

The telegraph is an apparatus for communication at a distance by signals. The word telegraph is derived from Greek word 'tele' and 'graph' which mean 'distant' and 'to write' respectively.

An electric telegraph apparatus consists of two parts: (*a*) a key for making and breaking an electric circuit, and (*b*) a sounder for producing clicks depending upon the manner in which the key is pressed.

The key is shown in Fig. 7.31.

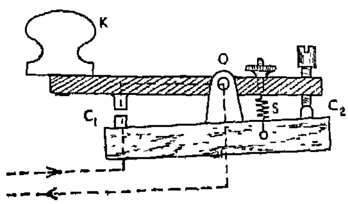


Fig. 31. Telegraph key (broken line shows the path of the current when the key is depressed).

A metal lever turns on an axis passing through O. On both sides of the axis, there are contacts C_1 and C_2. Spring S holds the lever up so that in the non-working condition, contact C_1 remains open. When the key K is pressed, contact C_1 closes.

The sounder is shown in Fig. 7.32. It consists of an electromagnet and a lever L fixed on an axis. One of its arms carries an iron armature while the other arm is being held up by a spring.

When the key is closed, a current flows through the electromagnet of

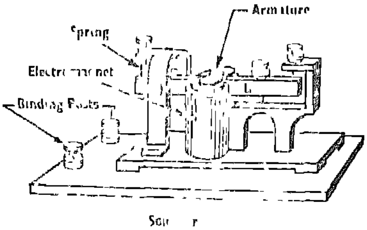


Fig. 7.32.

the sounder. This magnetizes the iron core. These cores attract the armature. In course of being attracted, the armature strikes the sounder and produces a click. When the key is opened, the current ceases to flow through the winding of the electromagnet and consequently the spring pulls back the armature and thus another click is produced.

Telegraphic message is sent according to the Morse code. This code is named after Samuel Morse, who invented the telegraph over 100 years ago. This code is a combination of dots and dashes representing different alphabets and numbers. For example, the signal for the letter '*a*' is one dot and one dash(.—), for the letter '*e*' one dot (.) and for the letter '*i*', two dots (. .), and so on.

Short time depression of the key represents a dot while a prolonged depression represents a dash.

To exchange telegrams, each station must have a sounder and a key. A telegraphic line has only one wire since the earth serves as a second wire.

It should be noted that some of the modern telegraphs are much more complicated in design than that which is described above. They print dots and dashes on tape and some of them even print letters directly on the tape. Such printed pieces on the tape are pasted on a telegram form and such telegrams are delivered to the addressee concerned.

§ 88. A Current bearing Conductor in a Magnetic Field

You have seen that when a magnetic needle is brought in the magnetic field of a magnet, it is displaced. You have also seen that a current bearing conductor produces a magnetic field around it. So, such a conductor behaves like a magnet. Now, let us examine the effect of a magnetic field on such a current bearing conductor. For this, let us do the following experiment.

Suspend a conductor by two insulated wires between the poles of a horse-shoe magnet as shown in Fig. 7.33*a*. Connect the wires to a battery through a switch. Close the switch and observe the action on the conductor. You will see that the conductor moves perpendicular to the magnetic lines of force of the

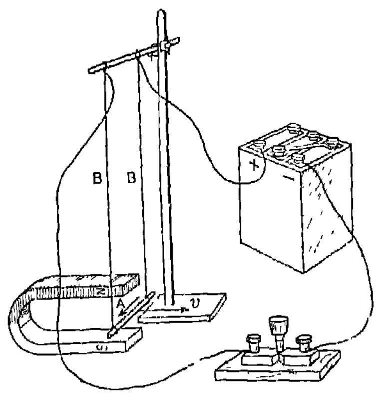


Fig. 33 (*a*). Schematic diagram of current carrying conductor in a magnetic field. The conductor moves towards the right when the direction of the magnetic field is downwards.

magnetic field between the poles. This indicates that a force acts upon a current bearing conductor placed in a magnetic field. Now change the direction of the current flow in the conductor by interchanging the connection of the wires to the terminals of the battery and observe the effect on the conductor. This time, the conductor is found to move in the opposite direction.

From the above experiment we conclude that the *direction of force acting on a current bearing conductor placed in a magnetic field depends upon the direction of the flow of the current in the conductor.*

Now turn the horse shoe magnet by 180° keeping the conductor in between the poles of the magnet. By doing so, you have interchanged the positions of N and S poles of the magnet and thereby changed the direction of the lines of force of the magnetic field. Now switch on the current in the conductor and observe the effect on it. You will find it to be deflected in opposite direction to the previous one (Fig. 7.33*b*).

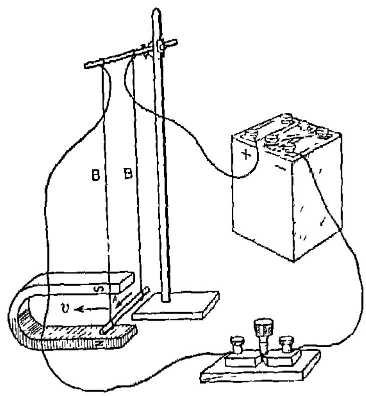


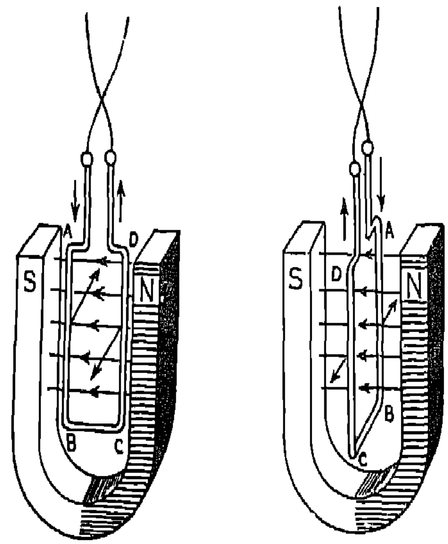
Fig. 7 33 (*b*). Schematic diagram of current carrying conductor in a magnetic field. The conductor moves towards the left when the direction of the magnetic field is upward.

So, we conclude that *the direction of the force upon the current bearing conductor placed in a magnetic field depends upon the direction of the magnetic field also.*

The direction of a force acting upon a current bearing conductor placed in a magnetic field thus depends on two factors: (*i*) the

direction of the current in the conductor, and (*ii*) the direction of the lines of force of the magnetic field in which the conductor is situated.

It has also been found from experiments that the direction of this force is perpendicular to both, the direction of the magnetic field and the direction of the current in the conductor.



(*a*) (*b*

Fig. 7.34. Force acting upon a current carrying loop placed in a magnetic field.

Let us now observe how a current bearing rectangular wire loop is acted upon by a magnetic field. For this, suspend a rectangular wire loop in a magnetic field between the two poles of a magnet and pass a current through it (Fig. 7.34).

On doing so we see that the loop simply rotates about its suspension at its axis to have its plane perpendicular to the lines of the magnetic field of the magnet. So, it seems that the loop is acted upon by a torque due to a pair of forces of equal magnitude and opposite directions. These two equal but oppositely directed forces act on the two conducting arms *AB* and *CD* of the rectangular loop which are carrying currents in opposite directions and are placed in the same magnetic field.

Rotation of a loop in a magnetic field has very wide use in construction of electrical motors, ammeters and voltmeters.

CHAPTER VIII

Nuclear Energy

§ 89. Natural Radioactivity

The discovery of radioactivity was a major step in the development of the science of atomic structure. At the end of the 19th century the French scientist Becquerel found that the compounds of uranium, placed on a photographic plate covered with black paper, emitted radiations which after a few days produced a shadow picture on it.

Pierre Curie.

It was soon discovered that the property of emitting penetrating radiations is not confined to uranium and its compounds. Some other minerals had the same property. Such substances are said to be *radioactive*, and the property itself *radioactivity*.

Great merit in the study of radioactivity goes to the prominent scientists Marie (*Sklodowska*) and Pierre Curie. From several tons of uranium pitch-blende they managed to isolate about 1 g of an unknown intensely radioactive mineral, the radioactivity of which turned out to be several million times higher than that of uranium. They named the element *radium* (from radius-ray). Even one 10,000 millionth fraction of a gram of this metal can be detected by its radioactivity.

Radiation produced by radium affects photographic plates, brings about ionization of gases, makes air an electric conductor and passes through thin metal plates. Heavy metals, lead, for instance, absorb this radiation.

Marie Sklodowska Curie.

Ernest Rutherford.

Radium and other radioactive substances continuously emit radiation. Due to this, radium is always somewhat warmer than the surrounding objects. In an hour's time 1 g of this metal produces nearly 140 calories.

When the phenomenon of radioactivity was discovered, the question of the nature of radiation in radioactive substances arose. The British scientist Rutherford was the first to solve the problem.

When the rays from a radioactive material placed in a lead container with a narrow channel, pass through a strong electric field, some are bent in one direction, some are deflected in the opposite direction and some travel straight (Fig. 8.1).

These radiations were named *alpha* (α), *beta* (β), and *gamma* (γ) rays after the first three letters of the Greek alphabet.

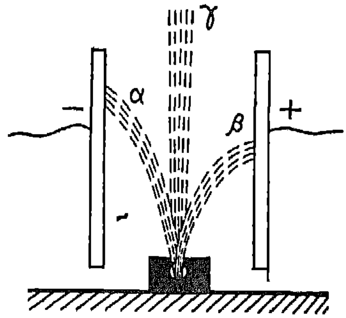


Fig. 8.1. Studying radium radiation in an electric field.

The alpha rays turned out to be a stream of helium nuclei emitted at a high velocity; they have a positive charge two times greater than that of hydrogen nuclei. The mass of the

helium nucleus is approximately four times greater than that of the hydrogen nucleus. Passing through an electric field alpha rays are deflected towards a negatively charged plate.

Beta rays are electrons ejected from the nuclei at very high velocities and are deflected in an electric field in the direction away from alpha rays.

Gamma rays do not deviate either in a magnetic or in an electric field. Their properties are identical to those of light.

In school conditions alpha particles can be observed with the help of a spinthariscope (Fig. 8.2), a

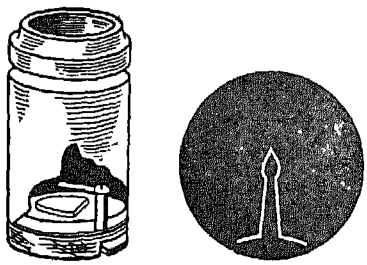


Fig. 8.2. Spinthariscope.

device consisting of a small tube the bottom of which is covered with zinc sulphide to form a fluorescent screen. When irradiated by a stream of alpha particles, it begins to scintillate. A small grain of radioactive substance is fixed just above the bottom level. In the upper part of the tube there is a lens.

While scrutinising the screen through the lens after getting used to the darkness, you will be able to see tiny greenish sparks flaring up. Each spark is produced when an alpha particle strikes the layer of zinc sulphide. You will not find it difficult to count the number of particles emitted on an average by the grain of radioactive substance in one second.

It is far more difficult to detect beta particles or electrons with the help of the device, because they produce only a faint glow.

§ 90. Nuclear Structure

Scientists did not stop at a mere experimental study of the discovered phenomenon; they tried to explain and substantiate it. Therefore, as soon as radioactivity was discovered, scientists set to get down to its roots.

Ernest Rutherford suggested that radioactivity was the result of atomic decay. A part of the atoms of a radioactive substance disintegrates due to *an unknown reason.* They seem to explode, with alpha and beta particles constituting the products of the decay—fragments of disintegrated atoms—and gamma rays as radiation.

Some radioactive substances disintegrate very slowly, others very quickly. Half the total number of

atoms of uranium disintegrates-over a period of several hundred million years, but half the number of radium atoms disintegrates in 1620 years, while in the case of radon, half the number of atoms disintegrates-in 3.8 years. There are radioactive substances, half the atoms of which decay in a mere millionth of a second.

We know that the atom consists of a nucleus and electrons. The phenomenon of radioactivity is an indication that the atomic nucleus in its turn consists of some more simple particles. What are they ?

Heisenberg first suggested that the nucleus of all elements consists of protons and neutrons. We have already discussed the proton above, but what is a neutron?

Neutron is a neutral particle whose mass is slightly greater than the mass of the proton.

The mass of the nucleus is equal to the mass of the protons and neutrons. Its charge is determined by the number of the protons alone, because neutrons are electrically neutral. There are no electrons in the nucleus. While disintegrating, however, certain radioactive substances emit electrons (beta particles). They are produced in the process of atomic disintegration. Having emitted an electron, one of the neutrons of the nucleus turns into a proton. Helium nuclei (alpha particles) which are formed during disintegration of a radioactive material, consist of two protons and two neutrons.

The nuclei of uranium, radium and other radioactive substances are very unstable. Some of them disintegrate emitting an electron or an alpha particle.

The emission of an alpha particle decreases the mass and positive charge of the nucleus.

The mass of the nucleus which emits an electron remains practically unchanged, but its positive charge increases.

The nucleus that has emitted a particle becomes the nucleus of another element. After emitting an alpha particle, a radium nucleus, for example, turns into a nucleus of the radioactive gas radon. A piece of radium placed into a soldered test tube turns after some time into helium and radon. The latter in its turn is transformed into other radioactive substances. The final product of the decay is lead which is not radioactive and, therefore, cannot disintegrate.

§ 91. Nuclear Energy

We have already said that the particles which are produced during

the disintegration of an atom of a radioactive element, move with great velocities. The velocity of alpha particles for instance is 1.6×10^7 m/sec., that of beta particles (electrons), 2×10^3 m/sec., i.e., it is close to that of light. Therefore, their kinetic energy is enormous.

What is the source of this energy? It would be only natural to conclude that it is the nuclei of atoms. Indeed, calculations prove that atomic nuclei store a tremendous amount of energy. This is called *nuclear energy*.

Disintegrating nuclei of radioactive substances release a huge amount of energy. It has been calculated that the stores of nuclear energy in coal are a million times greater than those of chemical energy.

However, nature has limited uantities of such elements as radium, and therefore the total energy they release is comparatively small.

In 1939, scientists discovered the fission of uranium nuclei by neutrons. This heralded the beginning of a new industry—nuclear energetics.

Experiments show that when uranium is irradiated by neutrons, the latter are captured by uranium nuclei which, as a result, become unstable and break roughly into two equal parts or nuclei. Fission fragments produced in the break-up process, fly off at enormous velocities. It is an explosion of an atomic nucleus followed by gamma radiation. Thus, nuclear energy is transformed during fission into the kinetic energy of fission fragments and into radioactive energy.

The energy released during the fission of one uranium nucleus is many times greater than the energy of alpha particles produced during the disintegration of radium. In the event of nuclear fission of all the atoms of 1 kg of uranium the released energy will be equal to that produced by burning 2,000 tons of coal or by exploding 2,000 tons of trinitrotoluene, a powerful explosive.

The fission fragments of uranium are radioactive and undergo a number of transmutations also, accompanied by the release of energy.

A number of elements are formed during the decay of uranium—barium, krypton, rubidium, cadmium among them.

Moreover, when the uranium nucleus disintegrates, one to three free neutrons per nucleus are emitted. The bombardment of the uranium nucleus by a neutron is schematically shown in Fig. 8.3.

The figure illustrates that when neutron n interacts with the uranium

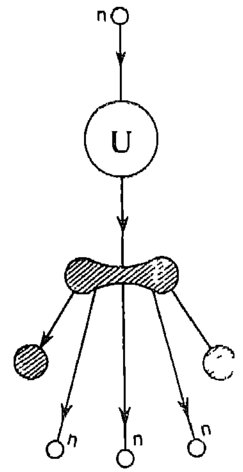


Fig. 8.3. Fission of uranium nucleus.

nucleus U, the latter breaks up into two fission fragments and three neutrons.

These, in turn, may cause two or three new fissions and as a result, their number and the number of disintegrating atoms steadily multiplies, thus starting a *chain reaction.*

The energy yielded by the chain reaction also increases and can become really enormous. The process quickly develops into a most terrifying explosion.

Fig. 8.4 gives a schematic diagram of a nuclear chain reaction. It should be borne in mind that a chain reaction occurs only during the fission of uranium, which has an atomic weight of 235. Natural uranium contains a mere 0,7% of it

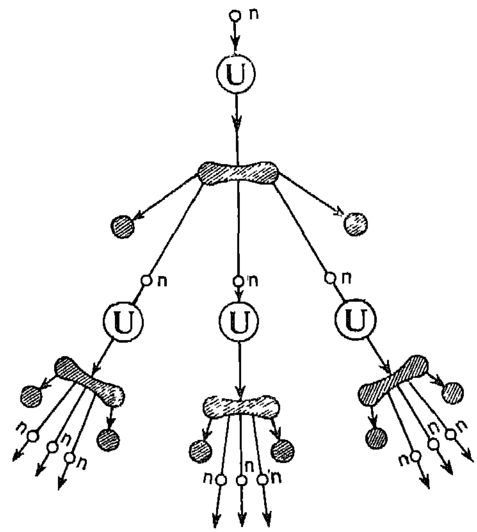


Fig. 8.4. Chain reaction

and a great deal of effort and money are spent in obtaining it in pure form.

Besides uranium-235, plutonium with atomic weight 239 also undergoes fission readily. No plutonium, however, exists in natural material and it has to be produced in special installations called *nuclear reactors.*

§ 93. Nuclear Energy for Peace

The discovery of nuclear energy was the greatest scientific feat of the 20th century.

The world's first 5,000 kW atomic station was built in the U.S.S.R. in 1954. Today several atomic power-stations generating hundreds of thousands of kilowatts of electric

energy are already in operation and several more powerful stations are under construction in the world In our own country a nuclear power station is to begin production of power in 1968 at Tarapur to supply energy to the states of Maharashtra and Gujarat. Another is being built at Kota in Rajasthan and a third one is planned to be built near Madras.

One of the main units of an atomic power-station is a nuclear reactor. It may be in the form of a huge cylinder (Fig. 8.5) into which

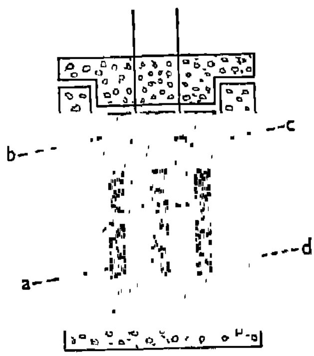


Fig. 8.5. Nuclear reactor.

fuel rods with a high content of uranium-235 are inserted.

Fission is accompanied by an energetic release of heat used to convert water into steam which is then fed to a steam turbine. The latter drives a generator which produces electricity.

We have given you only a brief description of the work of an atomic power-station.

Fig. 8.6 shows the diagram of a

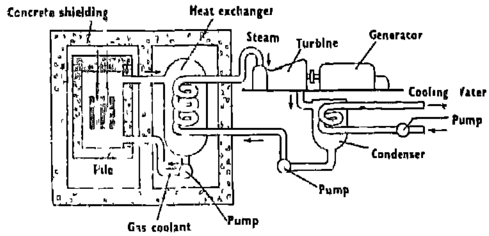


Fig. 8.6. Schematic diagram of a nuclear power plant.

sream power plant operated by an atomic pile. The fission of uranium produces heat to heat up the gas which in its turn heats up water in a steam boiler (heat exchanger) turning it into steam.

Nuclear power-plants can be used for propelling ships. The advantage of nuclear propelled ships lies in the fact that they do not have to carry large stores of fuel with them. Nuclear fuel does not take up much space and weighs very little. A small amount of fuel is enough to keep the ship at sea for a very long time.

Radioactive materials are being used increasingly and widely in medicine, especially for treating cancer.

Today nuclear energy is used in many branches of science and engineering.